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SOIL SCIENCE

Contents for June, 1918

THE INFLUENCE OF AMMONIUM SULFATE ON THE GERMINATION AND THE GROWTH OF BARLEY IN SAND AND SOIL CULTURES KEPT AT DIFFERENT MOISTURE CONTENTS AND AT VARIOUS OSMOTIC CONCENTRATIONS OF THE SOIL SOLUTION[1]

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INTRODUCTION

An adequate supply of nitrogen in the soil is one of the most important questions in soil fertility. This is true not only as a theoretical consideration, nitrogen being one of necessary elements for plant growth, but also from the practical point of view, because nitrogen in normal times is the most expensive of the fertilizing materials.

The inorganic nitrogenous materials which are available for agricultural purposes are very limited in both variety and amount. We have nitrate of soda, the natural supply of which will necessarily be declining in the course of time; sulfate of ammonia, the manufacture of which as a by-product in the coal industries is rapidly expanding; and calcium nitrate and calcium cyanamid, as the products of fixation of atmospheric nitrogen with the aid of electrical energy.

There undoubtedly exist a set of conditions under which a given fertilizer acts at its best. It is believed that this optimum set of conditions is specific for each fertilizer, and that it may or may not be the same for different nitrogenous materials. It is of prime importance, therefore, that one should know the behavior of that fertilizer under different conditions that go to modify its action, so as to make it most effective in crop production.

The present study is made of ammonium sulfate in order to throw some light on its fertilizing value under some variable conditions as they may be found in agricultural practice.

REVIEW OF LITERATURE

Ammonium sulfate is one of the few salts regarding whose fertilizing value there exist so many divergent opinions. Since the middle of the last century, when Boussingault (26), Ville (231), and Lawes, Gilbert and Pugh (128) performed their celebrated experiments on the sources of nitrogen of vegetation, and up to the present time, the question remains in dispute whether ammoniacal nitrogen is equal or inferior in its efficiency to nitrate nitrogen. Establish-

[1] Submitted to the faculty of Rutgers College in partial fulfillment of the requirements for the degree of Doctor of Philosophy, May, 1918.

ing the fact that nitrate nitrogen can be utilized without first being converted into the ammonia form, Ville (231) has recorded at the same time that with potassium nitrate for the nitrogen supply the plants contained more nitrogen than those with the sal ammoniac (ammonium chloride). From this he concluded that for plant growth ammoniacal nitrogen was inferior to nitrate nitrogen.

With the progress of agricultural research there had accumulated a vast amount of literature recording the data which throw some light on the question of efficiency of ammoniacal nitrogen versus nitrate nitrogen for the growth and development of agricultural plants.

Lawes and Gilbert (129) were among the first to investigate the relative value of ammonium sulfate and sodium nitrate for the growth of field crops. Investigations with wheat and barley were started by them as early as 1852, followed by oats in 1876 and continued up the present time. Each crop was grown on the same plot year after year. The results, on the whole, show that for plant growth nitrate of soda is preferable to the ammoniacal nitrogen, which was supplied with a mixture of the equal amounts of ammonium sulfate and ammonium chloride.

In 1880 Wagner (248) proposed a pot method for studying the efficiency of different nitrogenous fertilizers and manures. He and his co-workers (249), 250, 251), over a period of many years studied these fertilizers on many soils in Germany with different crops. His general conclusion was that, if nitrate of soda nitrogen is given a value of 100, the ammonium sulfate nitrogen was equal to 90, taking all the crops and soils into consideration.

In this country the investigations in Pennsylvania (103, 104) are among the oldest on this subject. These experiments have been carried on since 1880 on field plots, on which a general field rotation is maintained. In the first ten years of the experiment (104) ammonium sulfate gave better results than nitrate of soda, but as an average for over thirty years (104), the nitrate of soda was superior to ammonium sulfate.

Similar results were obtained by the Massachusetts Agricultural Experiment Station. The data of 25 years (66) show that, under the conditions of the experiment, ammonium sulfate was only 88 per cent as efficient as nitrate of soda.

New Jersey's (135) 15-years results with all the crops in a 5-year rotation show that the efficiency of ammonium sulfate was equal to 84.6 in connection with minerals alone and 91.6 in connection with solid manure, leached, if a value of 100 is assigned to the nitrate of soda.

The investigations of the Rothamsted and the Woburn (238) stations in England, of Wagner and his co-workers in Germany, and of the New Jersey, Pennsylvania and Massachusetts stations in this country, are perhaps, among the most authoritative on the subject of efficiency of these two fertilizing materials. There are a host of others, who found the superiority in the value of nitrate of soda over that of ammonium sulfate for the nitrogenous fertilizer

and whose results are no less trustworthy than those that have been mentioned above.

Among these investigators can be mentioned Sachs and Knop (187), Towar (227), Grahl (75), Warington (254), Kirchner (118), Voorhees (242, 243, 244), Voorhees and Lipman (245, 246), Lipman and his associates (133, 134, 135, 136, 137 and 138), Grandeau (76, 77), Bolin (23, 24), Kretschmer (126), Feruglio (61), Grazia and Galdieri (79), Schneidewind (190, 191, 192, 193, 194, 195, 196), Ward (253), Cillis (42), Porter and Gaut (170), Chodat (41), Schulze (198), Schmoeger (189), Steiglich (214), Söderbaum (209, 212), Stutzer (216, 217), Schreiber (197), Bachmann (15), Crowther (49, 50), Gilchrist (70), Berry (20), Vanha (229), Rhodin (182), Bremer (32) (for top-dressing), Buchner (37), Svoboda (219), Hansen (84), Malpeaux (140, 141), Rindell (178), de Jong (110, 111), Patterson (165), Larsen (127), Parsons (164), Woods (269), Wheeler and Adams (261), Hunt and his co-workers (103, 104), Goessman (73), Brooks and his associates (33, 34), Tacke (222), Duggar and Caethen (55), Kelkar (114), Ballard and Volck (17), Gerlach (69), Bonomi (25), Voelcker (237, 240), Herke (98), (Kappen 113), Bauman (18), Niklevski (156), McClelland (148), Popp (169) and many others.

On the other hand, there are just as many men who have found ammonium sulfate to be either equal or superior to nitrate of soda in plant production. Among these investigators can be mentioned Hellriegel (94), Kloepfer (120, 121, 122), Kraus (123, 124, 125), Clausen (44, 45, 46), Rhodin (180, 181, 182, 183), Huston (106), Vikier (232), Bovell and D'Albuquerque (29), Kelkar (114), Bachman (11, 12, 13, 16), Otto (160, 161), Lilienthal (130, 131), Caruso (39), Voelcker (233, 235, 239), Kretschmer (126), Wein (260), Watts (256, 257), Sebelien (201), Weibull (259), Süchting (218), Bolin (24), Kleberger (119), Wagner (252) (on fire-holding power in tobacco), Söderbaum (210, 211), Buchner (37), Hendrick (97), Swanwick and Kinch (220, 221), Jackometti (108), Harper (85), Milburn (150), Nazari (155), Blobel (22), Bauwens (19), Harrison (88, 89), and others (90), Rawson (177), Gilchrist (71, 72), Greig (80), Mayer (146) D'Albuquerque and Bovel (51), Bovell (30), Wilcox, Kelley and Krauss (265), Orchinnikov (158), Damseaux (52), Malpeaux (141), Tempany (224), Stokes (215), Etheridge (57), Wright (270), Kelley (115, 116), Anstead (10), Gardner and Brown (64), Van Hoek and Ranwerda (230), Calvin (38), Milburn and Gaut (151), Gaul (67, 68), Kimbrough (117), Wehnert (258), Rindell (178), Mausberg (143, 144), Haselhoff (91), Easterby (56), Oswald and his associates (159), Hiltner and Lang (101), Lipman and his associates (137), von Feilitzen (60), Lipman and Gericke (130), Porter and McWilliam (171), Schmitz (188), and many others (1, 2, 3, 4, 5, 6, 7, 8, 9).

Comparing the names of these groups we find some of them to appear in both. In many different instances the results of the same men are sometimes in favor of nitrate of soda and sometimes in favor of sulfate of ammonia. In some cases the differences are insignificant, while in others they are very considerable. The inferiority of ammonium sulfate in the Rothamsted and the

Woburn experiments in England, and at the New Jersey, Pennsylvania, and Massachusetts stations in this country, are the most noteworthy. In every case of the field experiments the yield of crops grown with ammonium sulfate as the source of nitrogen was fair at the beginning. At the Pennsylvania Station where the soil contained a fair amount of lime, the yields for 10 years or more on the ammonium sulfate plots were larger than those on the nitrate of soda plots. The yields on the ammonium sulfate plots, however, declined in time. This naturally led to investigations as to what was the cause of this gradual decline in the efficiency of the ammonium sulfate. In nearly every case it is now attributed to a deficiency of lime in these soils, for when lime was applied to these soils either in the field or in pot tests there was a considerable increase in the crop yield. In this connection reference may be made to Voelcker (234, 241), who studied the soils at Woburn; Hall (81) at Rothamsted; Brown (35), Brown and his associates (36), White (262), and Gardner and his associates (65), in Pennsylvania; and Blair and McLean (21) in New Jersey. Ruprecht and Morse (184) studying the soils from Massachusetts experimental plats came to the conclusion that the ill effect of ammonium sulfate was due to the formation of sulfates of iron and alumium, which takes place in the absence of the available compounds of calcium.

It is curious enough that in several of these experiments no provision was made to replenish the lime in the soil, although other fertilizers were applied year after year. Since ammonium sulfate, from the very nature of the salt, has the tendency to increase the soil acidity, it caused the accumulation of acids in the soils to such an extent that normal crop growth was almost impossible. When some lime was added, however, as was the case in the Pennsylvania (262, 65) experiments, the yields of crops of the ammonium sulfate plots came nearly up to the normal.

Somewhat similar conditions affected Wagner's results (251). He worked with a great variety of soils, some of them very deficient in lime. Yet in experimenting with most of these soils, he, while applying both potassium and phosphorus, supplied no lime in any form. When lime was introduced in his pot experiments the results for ammonium sulfate improved considerably, sometimes exceeding those for sodium nitrate.

Experimenting with nitrate of soda, sulfate of ammonia, nitrate of lime and calcium cyanamid on Rothamsted soils, Hall (81) finds very little difference between these nitrogenous materials in so far as crop growth is concerned. The differences, if they exist, do not exceed 10 per cent of the total crop. Indeed, in most instances, when ammonium sulfate is compared with sodium nitrate the difference in their effectiveness for plant growth is very small. It is only in special cases, as pointed by Hall (82), as on very light sands, heavy clays and soils very short of lime, that secondary considerations do come in and modify the results of the experiment.

Again, it is universally recognized that nitrate of soda is a one-season fertilizer. For this reason in the 1-year experiments nitrate of soda and ammonium

sulfate are hardly comparable, since the latter has a considerable after-effect (113, 183, 15, 125, 93, 100, 255).

There is still another feature which may be mentioned in connection with the present discussion. Russell (186), speaks of the toxicity of ammonium sulfocyanide, which in former years was frequently an impurity in ammonium sulfate manufactured from gas liquor. When present in sufficient quantities it caused an injury to the plants. "It is rarely," says Russell (184), "if ever, found now." Just how much of some of the ill effect noticed in connection with the use of ammonium sulfate could be attributed to this cause is impossible to say at present. Yet, it could hardly be denied that the methods in the manufacture of this salt in the earlier days of the industry were more crude than they are now, and it is very possible, therefore, that some of the impurities did play some part in the effectiveness of this salt as a fertilizer.

Consideration may now be given to the form of nitrogen which can be best assimilated by plants. As early as 1867 Hampe (83) observed that the growth of plants with ammonium salts as the source of nitrogen was rather slow at first, but was accelerated later. A similar observation was reported by Wagner (247) a year later. Evidently, it was the starting point from which has gradually developed a notion that ammoniacal nitrogen could hardly be used as such. Since the ammonium salts are quickly converted into a nitrate form, it was later taken for granted that ammonium sulfate, for instance, could not be used as such. On this account, the efficiency of the nitrogen of this salt was considered to be impaired. If it were true, the argument would be a very sound one, for it takes some time for the nitrification to take place. Moreover, the change of the nitrogen from the ammonia to a nitrate form is hardly ever 100 per cent efficient.

The fallacy of the conception, however, is now fairly well established. Over 30 years ago Pitsch (168) demonstrated that with nitrification excluded oats can grow and normally develop with ammonium sulfate as its source of nitrogen. Since then a number of other investigators working with different plants and media have obtained similar results. For an extensive review of the literature on the subject reference may be made to an excellent article of Hutchison and Miller (107). Among the latest contributions, with further verification that higher plants can assimilate ammonia nitrogen directly, may be mentioned Pantanelli and Severini (162, 163), Petrov (167), Kalinkin (112), Periturin (166), Shulov (207), Ritman (179), Prianishnikov (174, 175, 176), and Morozov (154). It is true that some plants are found to be able to assimilate the ammonia nitrogen more readily than others. Nikolaeva (157), even reports that one of the lupines was unable at all to use ammonia nitrogen. Yet, in the majority of cases no difficulty was encountered in growing various higher plants without nitrates.

This fundamental question of the direct assimilation of ammonia nitrogen by agricultural plants is considerably modified in field practice by the fact previously mentioned that at least a portion of the ammonia nitrogen in most

of the common soils under normal cultivation is very quickly changed into nitrate nitrogen.

The conditions under which any fertilizer acts may modify the efficiency of that fertilizer to a considerable degree. The extreme variations in the effect of ammonium sulfate is often attributed to different conditions of the investigation.

Besides the reaction of the soil, already mentioned above, the time and the manner of the application, the character of the season, the moisture content of the soil, temperature, etc., are among the factors which may enhance or diminish the effectiveness of ammonium sulfate, as noticed by Bachmann (18). De Jong (109) has reported that the efficiency of ammonium sulfate was very high in very wet seasons, as compared with that of dry seasons. Pospisil (172), comparing ammonium sulfate with sodium nitrate during four years, two of which had dry and two wet growing seasons, found that in the dry seasons nitrate of soda gave better results than ammonium sulfate, and in the wet seasons ammonium sulfate was superior to sodium nitrate.

The relationship of moisture content of the soil to the yield of crop was studied by many investigators. Hellriegel (95) found that the best yield of barley grain in sand cultures was obtained at 40 per cent of water-holding capacity, while the best yield of straw was reached at 60 per cent. Wollny's (268) results show that the optimum moisture content of soils for several farm crops lies between 60 and 80 per cent of the water-holding capacity. Similar results are recorded by Mayer (145) who also found that in this respect there exist some variations for different agricultural crops. Von Seelhorst (202) has shown that the effectiveness of fertilizers increased with the increase in moisture content. Similar results were reported by Morgan (153) and Colebatch (47). Also de Grazia (78), Harris (87) and Pospisil (172) came to the same conclusion, namely, that the action of fertilizers is influenced by the moisture content.

Von Seelhorst, alone and with his associates (203, 204, 205), Prianishnikov (173), Hunter (105), Tulaikov (228), Widtsoe (263), Widtsoe and Merrill (264) also considerably contributed to our knowledge of the subject. The results of Mitscherlich (152), however, differ from those of other investigators in so far as they show that with potatoes, oats and peas grown in quartz sand, two soils and muck, the crop yield continued to increase with an increase of the water-holding capacity up to 100 per cent.

In view of the foregoing facts it seemed to be advisable to investigate more closely the relation of the moisture content of the soil to the effect of ammonium sulfate in the germination, growth and the development of some agricultural plant. How does a given agricultural plant, when subjected to different applications of the necessary, or even the unnecessary, elements that go to make plant tissue, react when the moisture supply is varied within the limits often met in normal field operations?

In order to throw some light on this question, which is important for its general theoretical interest, and also for the practical bearing on soil management, the present investigation was undertaken.

EFFECT OF MOISTURE CONTENT OF SEA SAND ON THE GROWTH OF BARLEY, WITH AMMONIUM SULFATE AS THE SOURCE OF NITROGEN

Procedure

In this work the chemically pure (Baker's analyzed) substances were used for the plant nutrients. The only exception was calcium carbonate, which was reprecipitated powder, U. S. P.

After some preliminary experiments the following procedure was adopted. The plants of barley were grown in pot cultures in sea sand as a medium. Four different series of pots were prepared, each consisting of 54 pots. The moisture content in the first series was kept at 20 per cent; in the second series, at 40 per cent; in the third series, at 60 per cent; and in the fourth series, at 80 per cent of the water-holding capacity. The water-holding capacity of the sand was 24.33 per cent (an average of three determinations), as determined by the funnel method. The pots were of glazed earthenware and were 25 cm. in height and 25 cm. in inside diameter. Two kilograms of sand was used in each pot. The hygroscopic moisture of the sea sand was only 0.05 per cent, and it was disregarded in calculating the amount of water to add to each pot. Table 1 gives the per cent and the total amount of water added to the pots of each series. To find the absolute per cent of water at which each series was kept it is only necessary to add the hygroscopic moisture (0.05 per cent) to the per cent given in the table.

TABLE 1

Moisture content in the sea sand cultures of different series

PER CENT OF WATER-HOLDING CAPACITY	PER CENT BASED ON DRY SAND	AMOUNT OF WATER PER POT
		cc.
20	4.86	97.2
40	9.72	194.4
60	14.58	291.6
80	19.44	388.8

The moisture content of the sea sand cultures was kept as nearly constant as possible by adding water every day. Every other day the pots were weighed and brought to the original moisture content. On the days when the pots were not weighed the water was added to each pot in approximate proportion to the water loss on the preceding day.

The sea sand contained practically no nutrient material, as will be seen from the growth of the plants in the control pots. The cultures, therefore, were treated with a complete nutrient solution. The treatment consisted of

ammonium sulfate, monopotassium phosphate, magnesium sulfate and ferrous sulfate. These ingredients were added in solution, while calcium carbonate was mixed with sand previously to the introduction of the solution. Besides the variations in the moisture content, the fertilizing materials were varied as follows: ammonium sulfate was added from 0.05 to 0.40 gm. per pot; calcium

TABLE 2

Application of salts per pot containing 2 kgm. of sea sand, and the calculated values in pounds per acre

POT NO.	$(NH_4)_2SO_4$		$CaCO_3$		KH_2PO_4		$MgSO_4$		$FeSO_4.7H_2O$		$NaNO_3$		$Ca(NO_3)_2$	
	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre
	gm.	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*
0														
1	0.05	50	0.50	500	0.40	400	0.20	200	0.05	50				
2	0.05	50	1.00	1000	0.40	400	0.20	200	0.05	50				
3	0.05	50	2.00	2000	0.40	400	0.20	200	0.05	50				
4	0.05	50	0.50	500	0.80	800	0.20	200	0.05	50				
5	0.05	50	1.00	1000	0.80	800	0.20	200	0.05	50				
6	0.05	50	2.00	2000	0.80	800	0.20	200	0.05	50				
7	0.10	100	0.50	500	0.40	400	0.20	200	0.50	50				
8	0.10	100	1.00	1000	0.40	400	0.20	200	0.05	50				
9	0.10	100	2.00	2000	0.40	400	0.20	200	0.05	50				
10	0.10	100	0.50	500	0.80	800	0.20	200	0.05	50				
11	0.10	100	1.00	1000	0.80	800	0.20	200	0.05	50				
12	0.10	100	2.00	2000	0.80	800	0.20	200	0.05	50				
13	0.20	200	0.50	500	0.40	400	0.20	200	0.05	50				
14	0.20	200	1.00	1000	0.40	400	0.20	200	0.50	50				
15	0.20	200	2.00	2000	0.40	400	0.20	200	0.50	50				
16	0.20	200	0.50	500	0.80	800	0.20	200	0.50	50				
17	0.20	200	1.00	1000	0.80	800	0.20	200	0.05	50				
18	0.20	200	2.00	2000	0.80	800	0.20	200	0.05	50				
19	0.40	400	0.50	500	0.40	400	0.20	200	0.05	50				
20	0.40	400	1.00	1000	0.40	400	0.20	200	0.05	50				
21	0.40	400	2.00	2000	0.40	400	0.20	200	0.05	50				
22	0.40	400	0.50	500	0.80	800	0.20	200	0.05	50				
23	0.40	400	1.00	1000	0.80	800	0.20	200	0.05	50				
24	0.40	400	2.00	2000	0.80	800	0.20	200	0.05	50				
L			3.00	3000	0.60	600	0.20	200	0.05	50	0.50	500		
S					0.60	600	1.00	1000	0.05	50			0.35	350

[1] L and S stand for Lipman's and Shive's cultures, respectively.

carbonate, from 0.05 gm. to 2.0 gm.; and monopotassium phosphate, from 0.4 gm. to 0.8 gm. per pot. The treatment of each pot is given in table 2, which also gives the values in pounds of different salts per acre, as based on 2,000,000 pounds of soil (approximate weight of an acre of soil 6 inches deep).

Besides the control pots, which were left untreated, two pots in each series designated as 20L, 40L, 60L, and 80L, respectively, were treated with a modified

TABLE 3

Dry weight of barley grown in sea sand cultures of different moisture contents, total water loss per pot, and amount of water required to produce 1 gm. of dry matter under different treatments of salts

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENTS
	A	B	Average	A	B	Average	Average
			Series of 20 per cent of water-holding capacity				
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
200	0.0415	0.0680	0.0558	200	219	210	3,763
201	0.2620	0.2700	0.2660	290	278	284	1,068
202	0.4150	0.3450	0.3800	403	417	410	1,078
203	0.3520	0.4575	0.4048	426	466	446	1,101
204	0.1240	0.2545	0.1893	169	246	208	1,098
205	0.2380	0.2900	0.2640	251	293	272	1,030
206	0.2820	0.3170	0.2995	339	331	335	1,119
207	0.2910	0.3285	0.3098	310	381	346	1,116
208	0.4880	0 4130	0.5405	468	429	449	991
209	0.5120	0.4250	0.4685	497	410	454	950
210	0.3100	0.3250	0.3175	306	413	370	1,166
211	0.2838	0.3998	0.3418	322	395	359	1,050
212	0.3230	0.4910	0.4070	369	432	401	985
213	0.4200	0.3317	0.3759	474	433	454	1,207
214	0.4740	0.5580	0.5110	514	541	528	1,033
215	0.2610	0.3160	0.2885	359	319	339	1,174
216	0.4200	0.4740	0.4470	413	432	423	946
217	0.3832	0.4400	0.4116	367	384	376	913
218	0.4330	0.1913	0.3122	398	222	310	993
219	0.4295	0.2625	0.3460	445	310	378	1,092
220	0.4980	0.5410	0.5195	518	623	571	1,099
221	0.4670	0.1920	0.3295	362	179	271	823
222	0.1995		0.1995	189		189	947
223	0.4230	0.2190	0.3210	332	213	273	850
224	0.3640	0.4885	0.4263	300	351	326	765
20S	0.4130	0.4260	0.4195	461	468	465	1,181
20L	0.4725	0.5825	0.5275	493	682	588	1,114
			Series of 40 per cent of water-holding capacity				
400	0.0710	0.0775	0 0743	543	522	533	7,174
401	0.2745	0.2545	0.2645	642	723	683	2,578
402	0.4260	0.3045	0.3653	674	685	680	1,861
403	0.3425	0.3325	0.3375	678	684	681	2,018
404	0.3015	0.2415	0.2715	667	546	607	2,236
405	0.3015	0.2865	0.2940	641	632	637	2,167
406	0.4745	0.2950	0.3848	705	622	664	1,725
407	0.4010	0.3615	0.3813	670	665	668	1,753
408	0.4730	0.4720	0.4715	721	779	750	1,591
409	0.5070	0.4540	0.4805	781	786	784	1,633
410	0.3620	0.2505	0.3060	634	590	612	2,000
411	0.4860	0.4985	0.4923	667	740	704	1,430
412	0.5565	0.5960	0.5763	873	748	811	1,406

TABLE 3—*Continued*

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENTS
	A	B	Average	A	B	Average	Average
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
413	0.7245	0.6405	0.6825	851	900	876	1,284
414	0.6585	0.6540	0.6563	873	852	865	1,320
415	0.6940	0.6860	0.6900	927	972	950	1,377
416	0.7655	0.6505	0.7080	760	768	764	1,079
417	0.6540	0.7135	0.6838	807	829	818	1,196
418	0.8415	0.6865	0.7640	1,038	905	972	1,272
419	0.4510	0.5840	0.5675	665	832	749	1,320
420	0.8530	0.7445	0.7988	1,092	1,042	1,067	1,335
421	0.4575	0.5570	0.5073	553	1,122	838	1,653
422	0.5318	0.6817	0.6068	696	674	685	1,128
423	1.1095	0.8130	0.9613	1,086	870	978	1,018
424	0.9665	0.9265	0.9465	1,165	1,017	1,091	1,152
40S	0.6455	0.6980	0.6718	823	893	858	1,277
40L	0.7316	0.8097	0.7707	1,112	1,117	1,115	1,446
Series of 60 per cent of water-holding capacity							
600	0.0600	0.0445	0.0523	828	713	771	14,742
601	0.1995	0.2010	0.2003	681	459	570	2,850
602	0.1490	0.2460	0.1975	504	621	573	2,901
603	0.2405	0.3040	0.2723	774	582	678	2,493
604	0.3150	0.2925	0.3038	874	642	758	2,493
605	0.4025	0.3410	0.3719	841	693	767	2,062
606	0.3455	0.4155	0.3805	831	851	841	2,210
607	0.3980	0.5660	0.4820	611	674	643	1,334
608	0.5755	0.6145	0.5950	730	858	794	1,320
609	0.6490	0.5060	0.5775	695	646	671	1,162
610	0.5405	0.4905	0.5155	678	555	617	1,197
611	0.5210	0.6000	0.5605	884	639	762	1,359
612	0.5432	0.7660	0.6546	870	833	852	1,321
613	1.0090	1.0380	1.0235	1,190	1,282	1,236	1,208
614	1.0115	1.2070	1.1093	1,233	1,329	1,281	1,155
615	1.1050	1.1980	1.1515	1,164	1,391	1,278	1,110
616	0.7430	0.8110	0.7770	1,088	965	1,027	1,644
617	0.9825	1.0700	1.0263	1,232	1,170	1,201	1,171
618	1.2555	0.9405	1.0980	1,294	1,143	1,219	1,111
619	1.1880	1.2350	1.2115	1,223	1,487	1,355	1,119
620	1.0870	0.8475	0.9673	1,376	1,293	1,335	1,385
621	1.2880	1.1260	1.2070	1,467	1,391	1,429	1,184
622	0.7095	1.2150	0.9623	992	1,168	1,080	1,123
623	1.1460	1.2220	1.1840	1,277	1,284	1,281	1,082
624	1.1090	1.1345	1.1218	1,505	1,496	1,501	1,338
60S	1.3695	1.4495	1.4095	1,347	1,420	1,384	982
60L	1.4877	1.5010	1.4944	1,893	2,245	2,068	1,383

TABLE 3—*Concluded*

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENTS
	A	B	Average	A	B	Average	Average
Series of 80 per cent water-holding capacity							
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
800	0.0700	0.0755	0.0728	721	791	756	10,385
801	0.5140	0.2975	0.4058	927	820	864	2,128
802	0.4895	0.4300	0.4598	958	986	972	2,113
803	0.5890	0.5045	0.5468	1,081	1,018	1,050	1,920
804	0.4200	0.3075	0.3637	950	825	888	2,440
805	0.4195	0.4360	0.4278	907	892	900	2,103
806	0.4350	0.5260	0.4805	947	1,029	988	2,059
807	0.5005	0.4605	0.4805	942	1,030	986	2,054
808	0.5370	0.7430	0.6400	970	1,014	992	1,550
809	0.8715	0.8915	0.8815	1,090	1,250	1,170	1,327
810	0.5965	0.5960	0.5963	980	956	968	1,624
811	0.6265	0.6468	0.6382	1,009	979	994	1,558
812	0.5270	0.7900	0.6585	1,044	1,089	1,067	1,620
813	0.9620	0.8580	0.9100	1,241	1,300	1,271	1,397
814	1.0820	1.0500	1.0660	1,358	1,511	1,435	1,346
815	1.1183	1.3403	1.2293	1,455	1,496	1,476	1,202
816	0.9765	0.4110	0.6938	1,290	966	1,128	1,625
817	0.7030	1.0745	0.8888	1,218	1,327	1,273	1,432
818	1.1850	1.0755	1.1303	1,456	1,348	1,402	1,241
819	1.0350	0.5582	0.7966	1,413	1,151	1,282	1,609
820	1.1460	0.5675	0.8568	1,572	1,155	1,364	1,592
821	1.4210	1.2405	1.3308	1,776	1,847	1,812	1,361
822	1.4510	1.2060	1.3285	1,504	1,391	1,448	1,090
823	1.5320	1.2978	1.4199	1,702	1,508	1,605	1,130
824	1.9940	1.4690	1.7318	2,055	1,802	1,929	1,114
80S	1.6375	1.0075	1.3225	1,584	1,575	1,580	1,194
80L	1.8393	1.4415	1.6404	2,908	2,355	2,632	1,605

Lipman's (136) formula, consisting of 0.5 gm. sodium nitrate, 3.0 gm. calcium carbonate, 0.6 gm. monopotassium phosphate and 0.05 gm. ferrous sulfate. For additional comparison, eight more cultures were treated with a nutrient solution, which approximately equals Shive's (206) culture R_5C_2, as added in a single application at 60 per cent of water-holding capacity. These cultures were designated as 20S, 40S,60S, and 80S, respectively.

The plants were germinated in moist sand and, when grown to about 2 inches in height, transplanted into pots. Six plants, selected for uniformity in transplanting, were grown in each pot. The plants were harvested after 30 days of growth in culture pots, dried in the oven for 2 days at 90°C. and then for 12 hours at 105°C. After cooling, the plants were weighed. The weights, together with data on transpired and evaporated water, and the water requirement of plants are given in table 3, and illustrated in figure 1.

Results and Discussions

On examining figure 1 and the values in table 3 one notices that there is a considerable variation in plant growth due to the different moisture contents under which the plants were grown. This is especially noticeable in culture pots from numbers 13 to 24 and including the cultures of Lipman (136) and of Shive (206). In some instances the variation between the culture pots kept at different percentages of moisture with the same fertilizer treatments is greater than the variations in the same series due to differences in applied fertilizer. In the majority of cases the yield from pots of the 20 per cent series is lower than that from the corresponding pots of the 40 per cent series. The

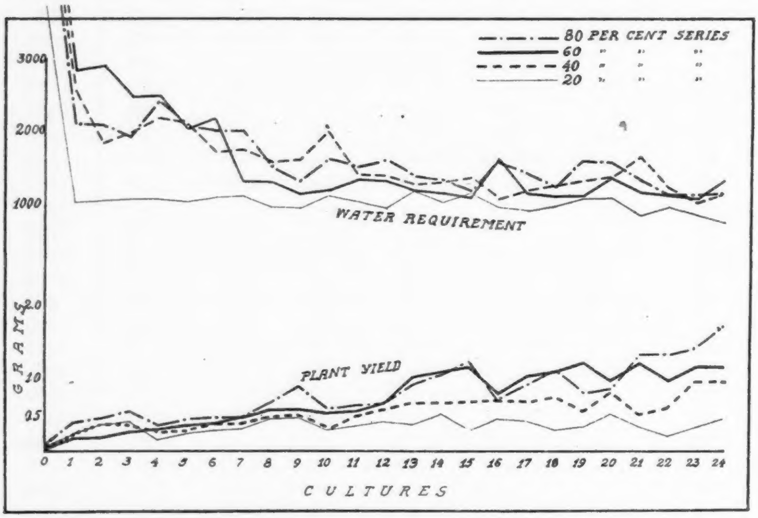

Fig. 1. The Variations in the Plant Yield of Sea Sand Cultures

Kept at different moisture contents and subjected to different fertilizer treatments, and the variations in the water requirement of plants under the same conditions; the different series of cultures were kept at the indicated percentages of the water-holding capacity

yield of the 60 per cent series is well above that of the 40 per cent series. The 80 per cent series was somewhat irregular in this respect. At times only did it exceed the corresponding values for the 60 per cent series. In the last three duplicate cultures with ammonium sulfate for the nitrogenous material the difference between pots of these two series was considerable and in favor of the 80 per cent series.

Another outstanding feature of figure 1 is the relation of plant growth to the water requirement of plants. Taking it as a whole, there is a tendency for the curves of top yields to go upward, and for the curves of water requirement to go proportionally downward. There are, of course, some irregularities and excep-

tions to this general tendency, but for the average of all series this inclination can easily be traced.

The surface of the sand cultures was open and, for this reason, no account was taken of the evaporation of water. Therefore, the transpiration of plants and the evaporation of water from the surface of sand in the pots were taken together in calculating the water requirement of plants. It is fully realized that these values do not represent exactly the water requirement of plants, for which only the transpiration through the plants is usually taken. But this procedure, perhaps, more nearly approaches the field conditions, where one deals with the total water loss from the soil, as influenced by both the intake of water by the roots of the plants and the surface evaporation.

In the series with moisture equal to 20 per cent of water-holding capacity, or 4.86 per cent of water based on air-dry sand, the growth of the plants was very small, regardless of the fertilizer treatment. The plants were stunted. The variations in the dry weight of six plants were from 0.1895 gm. in culture 204 to 0.5195 gm. in culture 220. The water requirement of the tops, or the grams of water transpired and evaporated per gram of dry matter produced, varied from 823 gm. in culture 221 to 1207 gm. in culture 213. In the series whose moisture content was equivalent to 40 per cent of the water-holding capacity the variations were greater, the maximum growth being 0.9613 gm. in culture 423 and the minimum, 0.2645 gm. in pot 401. The maximum and the minimum water requirements in this series corresponded with the minimum and the maximum growth of tops, respectively. That is to say, the plants with the best growth of tops had the lowest water requirement, and vice versa. The maximum plant growth in the series with 60 per cent of the water-holding capacity was 1.2115 gm. in culture 619, and the minimum growth 0.1975 gm. in culture 602. The last culture was the one with the highest water requirement, the figure being 2901 gm., while the lowest water requirement was in culture 623 with a value of 1082 gm. In the 80 per cent series the lowest production coincided with the highest water requirement, and the highest production with the lowest water requirement. In the first case it was culture 804 with 0.3637 gm. for the dry weight of the tops and 2440 gm. for the water requirement. In the second case it was culture 824, and the figures were 1.7315 gm. and 1114 gm., respectively.

The growth of plants from cultures 1 to 12 was small in all series, and the differences between two consecutive series inconsiderable. By consulting table 2, one notices that the backward growth was merely due to the insufficient supply of nitrogen.

One can trace further the relation of lime to the total yield of plants. The culture numbers 1, 4, 7, 10, 13, 16, 19, and 22 had the smallest application of calcium carbonate. In many cases, these pots were the lowest in dry matter produced as compared with the pots with the larger application of calcium carbonate, otherwise having been treated alike.

There was some response to the larger application of monopotassium phosphate, although the degree of the response was often very low.

The plants with 0.4 gm. of ammonium sulfate per pot had a tendency to lodge. It was not entirely due to the heavy growth, because the same general phenomena were noticed in every series, though the plants in the 20 per cent series even with this application of nitrogenous fertilizer had much poorer growth than those of other series with the lesser nitrogen supply. It is supposed that this was due to the poor balance of different components in the resultant nutrient solution. As the results of subsequent experiments show (see table 10 and the accompanied discussion), this supposition was perhaps correct.

It would not be out of place at this time to discuss briefly the behavior of ammonium sulfate in comparison with nitrate of soda, or calcium nitrate, as a source of nitrogen in this experiment. In the three series out of four there was always one or more cultures that exceed both Lipman's and Shive's cultures of the same series. Only the 60 per cent series failed in this respect. Both Lipman's and Shive's cultures in this series had better yields than any pots in the same series, having ammonium sulfate for the nitrogen supply. The comparison between these nitrogenous fertilizers was not made on a strictly equal basis. But it was not intended to study the efficiency of these different nitrogenous fertilizers for plant growth. It was merely used for comparison of ammonium sulfate under different moisture conditions with the formula of known behavior in the vegetative experiments.

The untreated pots were in every case the poorest in the yield of dry matter produced in that series. After transplanting the seedlings into the pots, the plants made hardly any growth at all. It seems that the seedlings could thrive only as long as the plant-food remained in the seed. The difference in moisture content did not cause any difference in their action.

EFFECT OF MOISTURE CONTENT OF SASSAFRAS LIGHT SANDY LOAM ON THE GROWTH OF BARLEY, WITH AMMONIUM SULFATE AS THE SOURCE OF NITROGEN

Procedure

The experiment which was described in the preceding pages, was repeated is a general way with the Sassafras light sandy loam for the medium of growth The plants were grown in the same pots, 2 kgm. of soil being used. In this instance the seeds were planted directly in the pots where they were to grow. Fifteen seeds were thus planted for the purpose, and, when germinated, they were thinned to 8 seedlings per pot. During the germination the soil moisture was kept at 60 per cent of the water-holding capacity. After thinning, the water was allowed to evaporate until it reached the required per cent. From this point on it was kept constant in the way previously described for the sea sand.

The water-holding capacity of the soil was 27.7 per cent, as determined by the funnel method. Table 4 gives the per cent of moisture at which the dif-

ferent series of pots were kept and also the total amount of water maintained in the pots of each series. The hygroscopic moisture of the soil is 0.94 per cent, based on oven-dry soil.

The fertilizer treatment of the different pots was precisely the same as given in table 2 for the sea sand. Aside from the fact that some plant-food was available in the soil itself, all other relations were maintained in the same manner as in the case of the sea sand in the foregoing experiment.

The plants were harvested after 30 days of growth, beginning with the day when the moisture content of every series was brought to the required level. The results are presented in table 5 and illustrated with figure 2, following the procedure adopted for the experiment described above.

Results and discussion

Looking over table 5 and figure 2 and comparing them with table 3 and figure 1, one notices a considerable similarity between these two sets of values.

TABLE 4

Moisture content in Sassafras light sandy loam of different series

PER CENT OF WATER-HOLDING CAPACITY	PER CENT OF WATER BASED ON DRY SOIL	AMOUNT OF WATER PER POT
		cc.
20	5.54	110.8
40	11.08	221.6
60	16.62	332.4
80	22.16	443.2

Yet there are some differences which occur rather too consistently to be attributed to experimental error. The crop-yield curves of the different series run in the following order. The curve of the 20 per cent series is conspicuously low. The curves of the 40 and the 80 per cent series run fairly well together, while that of the 60 per cent series in most cases exceeds them all. In other words, the crop yield increased with the increase in the moisture content up to 60 per cent of the water-holding capacity, and then decreased with the further increase in the moisture. In this case the behavior of plants in the soil is somewhat different from that in the sea sand. It seems that the air supply is the cause of this phenomenon. In the sea sand, which naturally is more easily accessible to currents of air, the lack of aeration was not felt by the plants. In the soil, however, the aeration was somewhat slower, though the total air space remained greater than in the sand.

Another difference in the results of this experiment as compared with that of the sea sand lies in the response of plants to the application of lime. In most cases in the last three series, when nitrogen, potash and phosphorus remained the same, the smaller application of calcium carbonate gave as good a yield of barley as did the larger application. Indeed, in many cases the larger applications of calcium carbonate decreased the yield. A glance at figure 2 reveals this relation very clearly.

TABLE 5

Dry weight of barley grown in Sassafras light sandy loam of different moisture contents, total water loss per pot, and amount of water required to produce 1 gm. of dry matter under different treatments of salts

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENT
	A	B	Average	A	B	Average	Average
	Series of 20 per cent of water-holding capacity						
	gm.	gm.	gm.	gm.	gm.	gm.	gm.
200	0.3330	0.3430	0.3380	483	464	474	1,402
201	0.3450	0.4400	0.3925	480	529	505	1,287
202	0.5425	0.4353	0.4889	570	525	548	1,120
203	0.5635	0.3190	0.4413	539	478	509	1,100
204	0.5460	0.6525	0.5993	505	538	522	871
205	0.6500	0.5160	0.5830	529	497	513	880
206	0.7595	0.6140	0.6868	520	535	528	769
207	0.5760	0.5010	0.5385	552	487	520	966
208	0.5100	0.4645	0.4873	512	530	521	1,070
209	0.7050	0.4240	0.5645	579	529	554	982
210	0.7680	0.6720	0.7200	491	502	497	691
211	0.8980	0.6370	0.7675	544	505	525	684
212	0.5853	0.7338	0.6596	464	535	500	558
213	0.6110	0.5427	0.5769	485	522	504	873
214	0.3515	0.4837	0.4676	493	471	482	1,030
215	0.6940	0.5380	0.6160	548	531	540	877
216	0.9390	0.8560	0.8975	529	543	536	598
217	1.0580	0.9370	0.9975	548	537	543	545
218	0.8195	0.9885	0.9040	531	572	552	610
219	0.5825	0.4750	0.5288	501	461	481	909
220	0.5820	0.5795	0.5808	488	501	495	852
221	0.4030	1.1745	0.7888	464	655	560	710
222	0.9708	1.0268	0.9988	532	520	526	527
223	1.0248	0.9997	1.0123	541	524	533	527
224	1.0248	1.2330	1.1289	554	606	580	514
20S	0.8710	0.7400	0.8055	546	491	519	645
20L	0.7875	0.6802	0.7339	505	491	498	679
	Series of 40 per cent of water-holding capacity						
400	0.7175	0.6440	0.6808	961	853	907	1,332
401	1.0435	1.0350	1.0395	949	989	969	933
402	1.1090	1.1860	1.1475	957	971	964	855
403	1.0235	1.1050	1.0643	990	907	949	892
404	1.1635	1.2190	1.1913	992	1,028	1,010	923
405	1.2520	1.0730	1.1625	999	927	963	829
406	1.0370	1.1080	1.0725	906	864	885	825
407	1.3050	1.3045	1.3048	983	918	951	728
408	1.2070	1.3100	1.2585	959	956	958	761
409	1.3220	1.2230	1.2725	1,003	874	939	738
410	1.3775	1.4740	1.4258	976	947	962	674

TABLE 5—*Continued*

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENT
	A	B	Average	A	B	Average	Average
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
411	1.1700	1.4020	1.2860	980	893	937	728
412	1.4040	1.5990	1.5015	959	981	970	646
413	1.6050	1.6760	1.6405	998	963	981	598
414	1.6515	1.3265	1.4890	1,037	894	966	649
415	1.1615	1.2405	1.2010	890	792	841	700
416	1.7795	1.7395	1.7595	1,003	1,009	1,006	571
417	1.5590	1.8030	1.6810	1,044	994	1,019	607
418	1.3280	1.8150	1.5715	905	1,037	971	618
419	1.9420	2.0805	2.0113	1,069	1,013	1,041	518
420	2.0040	2.1850	2.0945	1,084	1,072	1,078	515
421	1.8335	2.0245	1.9290	1,034	1,020	1,027	532
422	2.1600	2.2327	2.1964	1,046	1,037	1,042	474
423	2.1625	1.9178	2.0402	1,079	951	1,015	498
424	2.1550	2.0510	2.1030	1,030	1,056	1,043	496
40S	1.2800	1.6970	1.4885	968	975	972	653
40L	1.9880	1.9980	1.9930	1,060	1,084	1,072	538
Series of 60 per cent of water-holding capacity							
600	0.7920	0.6540	0.7230	1,100	998	1,049	1,445
601	1.0405	1.1150	1.0778	1,156	1,136	1,146	1,062
602	1.1965	1.1525	1.1745	1,159	1,176	1,168	997
603	1.0718	1.1540	1.1129	991	1,090	1,041	934
604	1.1110	1.2310	1.1710	1,218	1,139	1,179	1,006
605	1.0475	1.1825	1.1150	1,123	1,167	1,145	1,027
606	1.1620	1.1610	1.1610	1,097	1,065	1,081	931
607	1.3200	1.5485	1.4343	1,064	1,216	1,140	795
608	1.3635	1.3100	1.3368	1,150	1,217	1,184	886
609	1.3140	1.3335	1.3438	1,081	1,078	1,079	803
610	1.3770	1.4245	1.4008	1,113	1,088	1,101	786
611	1.3500	1.3830	1.3665	1,148	1,138	1,143	837
612	1.4540	1.2660	1.3600	1,143	1,030	1,087	799
613	1.8585	1.6940	1.7763	1,191	1,247	1,219	687
614	1.5980	1.2960	1.4470	1,142	1,082	1,112	768
615	1.5675	1.6820	1.6248	1,145	1,228	1,187	730
616	2.0680	1.8975	1.9828	1,293	1,115	1,204	607
617	1.9200	1.9050	1.9125	1,282	1,220	1,251	654
618	1.9310	1.8875	1.9093	1,275	1,179	1,227	643
619	2.2240	2.4495	2.3368	1,353	1,470	1,412	604
620	2.1815	2.5025	2.3420	1,287	1,517	1,402	599
621	2.3350	2.2715	2.3033	1,441	1,408	1,425	619
622	2.5975	2.6245	2.6110	1,433	1,557	1,495	573
623	2.4020	2.4695	2.4358	1,506	1,335	1,421	583
624	2.5230	2.4092	2.4661	1,413	1,357	1,385	562
60S	1.9780	1.8600	1.9190	1,459	1,224	1,342	699
60L	2.3820	2.7240	2.5530	1,632	1,731	1,682	658

TABLE 5—*Concluded*

POT NO.	DRY WEIGHT OF TOPS			TRANSPIRATION AND EVAPORATION			WATER REQUIREMENT
	A	B	Average	A	B	Average	Average
	Series of 80 per cent of water-holding capacity						
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
800	0.6320	0.7135	0.6728	839	907	873	1,297
801	0.9545	1.0500	1.0023	1,017	1,017	1,017	1,014
802	0.9165	1.0065	0.9615	982	991	987	1,027
803	0.9665	1.0530	1.0098	1,104	1,113	1,109	1,098
804	0.9985	0.9685	0.9835	1,031	999	1,015	1,032
805	0.9547	0.8880	0.9214	1,026	980	1,003	1,090
806	0.9210	1.0085	0.9648	1,033	1,023	1,028	1,065
807	1.1420	1.3005	1.2213	1,033	1,313	1,173	961
808	1.1250	1.3420	1.2335	1,115	1,213	1,164	944
809	1.1775	1.2470	1.2123	1,183	1,227	1,205	995
810	1.0172	1.2550	1.1361	1,164	960	1,012	979
811	1.1920	1.1695	1.1808	1,149	1,059	1,104	935
812	1.1075	1.1800	1.1438	1,108	1,101	1,105	965
813	1.7750	1.6610	1.7180	1,285	1,279	1,282	946
814	1.6450	1.7190	1.6820	1,294	1,426	1,360	809
815		1.5795	1.5795	1,162	1,344	1,344	793
816	1.5780	1.6670	1.6225	1,255	1,222	1,239	764
817	1.7100	1.5270	1.6185	1,334	1,112	1,223	756
818	1.6230	1.6830	1.6530	1,416	1,284	1,350	816
819	1.9720	2.1955	2.0838	1,450	1,587	1,519	729
820	2.1470	2.0225	2.0348	1,560	1,603	1,582	777
821	1.9310		1.9310	1,565	1,393	1,479	845
822	1.9328	1.8635	1.8982	1,398	1,311	1,355	714
823	2.0530	2.2350	2.1440	1,497	1,601	1,549	722
824	2.1655	1.9000	2.0328	1,592	1,441	1,517	746
80S	1.5695	1.4655	1.5175	1,699	1,707	1,703	1,122
80L	1.7460	1.8925	1.8193	1,523	1,707	1,615	890

All curves tend to go upward, thus showing the increasing response to the application of nitrogen. With 0.2-gm. and 0.4-gm. applications of ammonium sulfate per pot there is some difference in plant growth with the different applications of monopotassium phosphate, the greater yield being produced with the large application of this salt. This tendency is noticeable with every moisture content. No such inclination can be traced when ammonium sulfate was added only to the extent of 0.05 gm. or 0.1 gm. per pot. The limiting factor in the first 12 pots, common in all series, was nitrogen. This fact, perhaps, accounts for the lack of appreciable influence of either calcium carbonate or monopotassium phosphate.

The relation of the total yield of barley to the water requirement of plants is very apparent. With the increase in total yield there is a decrease in the amount of water required to grow a unit of dry matter. This is true in every series, but it does not hold true when one compares the cultures on the basis of

moisture content. The curve for the values of water requirement of the 20 per cent series is very erratic. The remaining three series are quite consistent in their behavior. Taking into consideration only these three series, the greatest amount of water needed to produce a unit of dry matter is noticed in the 80 per cent series; this is followed by the 60 per cent series; and the 40 per cent series is the most economical in the use of water.

In the 20 and the 40 per cent series the cultures of the minimum yield correspond with the highest water requirement of plants, and the cultures of the

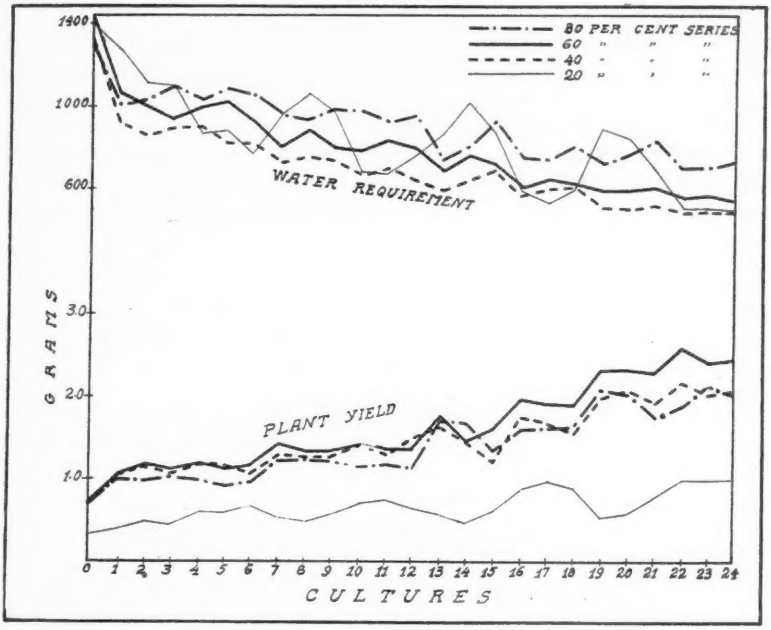

FIG. 2. THE VARIATIONS IN THE PLANT YIELD OF SASSAFRAS LIGHT SANDY LOAM

Kept at different moisture contents and subjected to different fertilizer treatments, and the variations in the water requirement of plants under the same conditions; the different series of cultures were kept at the indicated percentages of water-holding capacity

maximum yield coincide with the lowest water requirement. In the 60 per cent series the culture of the minimum yield has the highest water requirement, while the culture of the maximum yield is the second from the lowest in the water requirement. In the 80 per cent series the coincidence of lowest yield with the highest water requirement is not so exact, although quite similar.

Taking all the series together, there is a general tendency for the crop yield curves to go upward, beginning with culture 1, while for the curves of water

requirement of the plants the tendency is to go proportionally downward. This relation is quite apparent from figure 2.

The control pots, or the pots which remained untreated, had in every case the lowest yield of the series. Of the control cultures, those of the 20 per cent series had the lowest yield, while the pots of the remaining three series had practically the same yield (see no. 1 in figure 2). It seems that, beginning with the moisture content of 40 per cent of the water-holding capacity, the limiting factor was neither water nor aeration, but plant-food; for, beginning with culture 1, there was some response to the application of either one salt or another.

The standard cultures, which were represented by Lipman's (136) and Shive's (206) culture formulas, were designated by letters L and S, respectively, prefixed to the culture numbers. In the plant yields they followed the general rule for cultures with ammonium sulfate. The highest yield for both standard cultures was with the 60 per cent moisture, followed by 40 and 80 per cent in close succession, while the yield of the 20 per cent series was the lowest. In every series there were one or more cultures which exceeded in yield both the Lipman and the Shive cultures.

THE OSMOTIC CONCENTRATION OF THE SOIL SOLUTION, AND ITS EFFECT ON THE GROWTH OF BARLEY PLANTS IN SEA SAND AND SASSAFRAS LIGHT SANDY LOAM

Refering again to the figures 1 and 2, one observes that the curves for the values of the 20 per cent series stand all by themselves. This is especially true in the case of the Sassafras light sandy loam, and also in the sea sand, where nitrogen was supplied in abundance.

The question naturally arises: Why was there so great a difference in plant growth between the 20 per cent and the 40 per cent series in comparison with the differences between the 40 and 60 per cent series, and, again, between the 60 and 80 per cent series?

The answer that suggests itself is that it might be due to the increase in osmotic pressure of the solution in which the plants are grown. In preparing the cultures of the different series the same amount of salts was taken for the corresponding number of each series. The solution for the 40 per cent series, therefore, was less concentrated than that for the 20 per cent series. The solution of the 60 per cent series was less concentrated than that of the 40 per cent series; and, finally, the solution of the 80 per cent series was the most dilute of the four series. This natural progress in dilution of the nutrient solution takes place in a liquid medium, or in the homogenous system. Shall it proceed in the same way, when a solid material is introduced into the system? In other words, shall the increase in concentration in the soil solution due to the application of the nutrient solution be proportional to the decrease in the total moisture content of the soil or sand?

TABLE 6

Osmotic concentration of nutrient solutions, the sea sand treated with these solutions and the sand at the end of the vegetation experiment

	FREEZING-POINT DEPRESSION OF SAND TREATED WITH THE NUTRIENT SOLUTIONS (BEFORE GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF SAND TREATED WITH THE NUTRIENT SOLUTIONS (AFTER GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF THE ORIGINAL NUTRIENT SOLUTION			OSMOTIC CONCENTRATION
	°C. 1	°C. 2	°C. average	Atmospheres average	°C. 1	°C. 2	°C. average	Atmospheres average	°C. 1	°C. 2	°C. average	Atmospheres average
Series of 20 per cent of water-holding capacity												
200	0.058	0.050	0.054	0.651	0.010	0.011	0.011	0.133				
201	0.340	0.342	0.341	4.100	0.093	0.078	0.086	1.037	0.165	0.169	0.167	2.014
202	0.345	0.321	0.333	4.014	0.083	0.083	0.083	1.001				
203	0.300	0.305	0.303	3.652	0.085	0.093	0.089	1.084				
207	0.363	0.320	0.342	4.122	0.111	0.101	0.106	1.278	0.185	0.191	0.188	2.267
208	0.348	0.332	0.340	4.098	0.102	0.108	0.105	1.266				
209	0.323	0.335	0.329	3.966	0.110	0.100	0.105	1.266				
213	0.508	0.503	0.506	6.097	0.158	0.152	0.155	1.869	0.223	0.223	0.223	2.688
214	0.495	0.507	0.501	6.037	0.160	0.152	0.156	1.881				
215	0.400	0.405	0.403	4.857	0.143	0.143	0.143	1.724				
219	0.510	0.520	0.515	6.205	0.201	0.197	0.199	2.400	0.282	0.284	0.283	3.401
220	0.500	0.472	0.486	5.856	0.220	0.211	0.216	2.604				
221	0.485	0.510	0.496	5.976	0.162	0.167	0.165	1.990				
Series of 40 per cent of water-holding capacity												
400	0.030	0.030	0.030	0.362	0.008	0.008	0.008	0.096				
401	0.102	0.101	0.102	1.230	0.042	0.032	0.037	0.446	0.105	0.101	0.103	1.242
402	0.104	0.102	0.103	1.242	0.030	0.028	0.029	0.350				
403	0.102	0.102	0.102	1.230	0.027	0.038	0.033	0.398				
407	0.150	0.143	0.147	1.772	0.052	0.052	0.052	0.627	0.117	0.117	0.117	1.411
408	0.128	0.148	0.138	1.664	0.029	0.030	0.030	0.362				
409	0.142	0.130	0.136	1.640	0.047	0.040	0.044	0.530				
413	0.165	0.170	0.168	2.026	0.037	0.037	0.037	0.446	0.123	0.125	0.124	1.495
414	0.165	0.158	0.162	1.954	0.057	0.055	0.056	0.675				
415	0.162	0.155	0.158	1.906	0.056	0.055	0.056	0.675				
419	0.217	0.217	0.217	2.616	0.098	0.108	0.103	1.242	0.148	0.149	0.149	1.797
420	0.222	0.197	0.209	2.520	0.075	0.075	0.075	0.904				
421	0.222	0.222	0.222	2.676	0.088	0.113	0.101	1.218				
Series of 60 per cent of water-holding capacity												
600	0.014	0.012	0.013	0.157								
601	0.077	0.075	0.076	0.916	0.054	0.055	0.055	0.663	0.050	0.050	0.050	0.603
602	0.072	0.072	0.072	0.868	0.052	0.060	0.056	0.675				
603	0.068	0.067	0.068	0.820	0.062	0.062	0.062	0.748				
607	0.080	0.081	0.080	0.965	0.036	0.034	0.035	0.422	0.065	0.065	0.065	0.784
608	0.084	0.085	0.085	1.025	0.034	0.032	0.033	0.398				
609	0.080	0.087	0.084	1.013	0.049	0.032	0.036	0.434				
613	0.129	0.124	0.126	1.519	0.070	0.067	0.069	0.832	0.080	0.080	0.080	0.965

TABLE 6—*Concluded*

	FREEZING-POINT DEPRESSION OF SAND TREATED WITH THE NUTRIENT SOLUTIONS (BEFORE GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF SAND TREATED WITH THE NUTRIENT SOLUTIONS (AFTER GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF THE ORIGINAL NUTRIENT SOLUTION			OSMOTIC CONCENTRATION
	°C. 1	°C. 2	°C. average	Atmospheres average	°C. 1	°C. 2	°C. average	Atmosphere average	°C. 1	°C. 2	°C. average	Atmospheres average
	Series of 60 per cent of water-holding capacity—Continued											
614	0.126	0.126	0.126	1.519	0.052	0.052	0.052	0.627				
615	0.126	0.122	0.124	1.495	0.062	0.061	0.062	0.748				
619	0.140	0.152	0.146	1.760	0.058	0.054	0.056	0.675	0.100	0.100	0.100	1.206
620	0.122	0.127	0.125	1.507	0.070	0.057	0.064	0.772				
621	0.129	0.127	0.128	1.434	0.057	0.057	0.057	0.687				
	Series of 80 per cent of water-holding capacity											
800	0.006	0.004	0.005	0.060	0.003	0.004	0.004	0.048				
801	0.053	0.059	0.056	0.675	0.035	0.025	0.030	0.362	0.043	0.043	0.043	0.518
802	0.057	0.057	0.057	0.687	0.035	0.032	0.034	0.410				
803	0.055	0.055	0.055	0.663	0.045	0.039	0.042	0.504				
807	0.075	0.068	0.072	0.868	0.035	0.035	0.035	0.422	0.051	0.053	0.052	0.627
808	0.075	0.073	0.074	0.892	0.033	0.031	0.032	0.386				
809	0.073	0.070	0.072	0.868	0.021	0.021	0.021	0.253				
813	0.080	0.078	0.079	0.953	0.028	0.028	0.028	0.338	0.065	0.065	0.065	0.784
814	0.077	0.070	0.074	0.892	0.030	0.024	0.027	0.326				
815	0.069	0.073	0.071	0.856	0.026	0.028	0.027	0.326				
819	0.110	0.101	0.106	1.278	0.025	0.025	0.025	0.301	0.080	0.080	0.080	0.965
820	0.101	0.090	0.096	1.158	0.030	0.026	0.028	0.334				
821	0.083	0.098	0.091	1.097	0.030	0.027	0.029	0.350				

Procedure

In order to answer these questions the osmotic concentration of the nutrient solutions before and after adding them to the sand or soil was determined by means of the freezing-point method. The solutions themselves were tested in the usual way by the cryoscopic method; and those in the sand or soil by the modification of the cryoscopic method, as outlined by Bouyoucos and McCool (28). The calculations were made with the aid of the table of Harris and Gortner (86). At the end of the vegetation experiment, immediately after harvesting the plants, the soil or the sand of the pots was brought to the original moisture content. Then the contents of the pot were emptied on a clean oil-cloth, the soil was thoroughly mixed and the samples were taken to test the osmotic concentration of the material. To determine the concentration of the soil solution before growing the plants the following procedure was adopted. Twenty-five grams of the soil treated with the proper amount of calcium carbonate was taken, mixed with the required amount of the nutrient solution, and placed into the freezing test tube. On the following day

TABLE 7

Osmotic concentration of nutrient solutions, the Sassafras light sandy loam treated with these solutions, and the same loam at the end of the vegetation experiment

	FREEZING-POINT DEPRESSION OF SOIL TREATED WITH NUTRIENT SOLUTION (BEFORE GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF SOIL TREATED WITH NUTRIENT SOLUTION (AFTER GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF THE ORIGINAL NUTRIENT SOLUTION			OSMOTIC CONCENTRATION
	°C. 1	°C. 2	°C. average	Atmospheres average	°C. 1	°C. 2	°C. average	Atmospheres average	°C. 1	°C. 2	°C. average	Atmospheres average
					Series of 20 per cent of water-holding capacity							
200	0.619	0.621	0.620	7.469	0.580	0.530	0.555	6.688				
201	0.653	0.658	0.656	7.902	0.615	0.620	0.618	7.445	0.155	0.155	0.155	1.869
202	0.663	0.652	0.658	7.927	0.652	0.622	0.637	7.674				
203	0.720	0.725	0.723	8.708	0.562	0.542	0.552	6.652				
207	0.703	0.728	0.716	8.624	0.587	0.585	0.586	7.060	0.166	0.164	0.165	1.990
208	0.705	0.635	0.670	8.071	0.635	0.612	0.624	7.517				
209	0.613	0.638	0.626	7.541	0.593	0.580	0.587	7.072				
213	0.677	0.708	0.693	8.348	0.590	0.630	0.610	7.349	0.189	0.187	0.188	2.267
214	0.712	0.722	0.717	8.636	0.690	0.610	0.650	7.830				
215	0.735	0.765	0.750	9.033	0.600	0.625	0.613	7.385				
219	0.764	0.799	0.782	9.418	0.675	0.668	0.672	8.095	0.248	0.250	0.249	3.002
220	0.771	0.749	0.760	9.154	0.690	0.707	0.699	8.420				
221	0.791	0.781	0.786	9.466	0.630	0.665	0.648	7.806				
					Series of 40 per cent of water-holding capacity							
400	0.119	0.124	0.122	1.471	0 108	0.107	0.108	1.303				
401	0.140	0.150	0.145	1.748	0.121	0.125	0.123	1.483	0.089	0.091	0.090	1.085
402	0.160	0.175	0.168	2.022	0.124	0.126	0.125	1.507				
403	0.147	0.170	0.159	1.918	0.119		0.119	1.435				
407	0.160	0.151	0.156	1.881	0.116	0.111	0.114	1.363	0.095	0.095	0.095	1.145
408	0.160	0.151	0.156	1.881	0.106	0.116	0.111	1.339				
409	0.150	0.149	0.150	1.809	0.111	0.101	0.106	1.278				
413	0.154	0.171	0.163	1.966	0.149	0.142	0.145	1.748	0.112	0.105	0.109	1.315
414	0.188	0.151	0.170	2.050	0.139	0.128	0.134	1.506				
415	0.163	0.146	0.155	1.869	0.112	0.107	0.110	1.327				
419	0.164	0.156	0.160	1.930	0.152	0.160	0.156	1.881	0.140	0.140	0.140	1.688
420	0.164	0.169	0.166	2.002	0.153	0.145	0.149	1.797				
421	0.166	0.161	0.164	1.978	0.123	0.139	0.131	1.470				
					Series of 60 per cent of water-holding capacity							
600	0.018	0.016	0.017	0.205	0.010	0.008	0.009	0.109				
601	0.042	0.041	0.042	0.506	0.018	0.020	0.019	0.229	0.061	0.063	0.062	0.748
602	0.042	0.040	0.041	0.494	0.019	0.019	0.019	0.229				
603	0.041	0.042	0.042	0.506	0.018	0.019	0.019	0.229				
607	0.045	0.045	0.045	0.542	0.028	0.032	0.030	0.362	0.070	0.067	0.069	0.832
608	0.046	0.049	0.047	0.566	0.024	0.024	0.024	0.289				
609	0.049	0.049	0.049	0.590	0.020	0.022	0.021	0.253				
613	0.045	0.044	0.045	0.542	0.032	0.022	0.027	0.325	0.072	0.071	0.072	0.868
614	0.051	0.051	0.051	0.614	0.020	0.027	0.024	0.289				

TABLE 7—*Concluded*

	FREEZING-POINT DEPRESSION OF SOIL TREATED WITH NUTRIENT SOLUTION (BEFORE GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF SOIL TREATED WITH NUTRIENT SOLUTION (AFTER GROWING CROP)			OSMOTIC CONCENTRATION	FREEZING-POINT DEPRESSION OF THE ORIGINAL NUTRIENT SOLUTION			OSMOTIC CONCENTRATION
	°C. 1	°C. 2	°C. average	Atmosphere average	°C. 1	°C. 2	°C. average	Atmosphere average	°C. 1	°C. 2	°C. average	Atmospheres average
	Series of 60 per cent of water-holding capacity—Continued											
615	0.045	0.049	0.047	0.566	0.027	0.027	0.027	0.325				
619	0.062	0.060	0.061	0.736	0.037	0.040	0.039	0.470	0.101	0.107	0.104	1.254
620	0.064	0.068	0.066	0.796	0.032	0.037	0.035	0.422				
621	0.068	0.073	0.071	0.856	0.029	0.036	0.033	0.398				
	Series of 80 per cent of water-holding capacity											
800	0.010	0.008	0.009	0.119	0.009	0.009	0.009	0.109				
801	0.028	0.029	0.029	0.350	0.017	0.017	0.017	0.205	0.052	0.052	0.052	0.627
802	0.028	0.023	0.026	0.313	0.015	0.017	0.016	0.193				
803	0.023	0.028	0.026	0.313	0.018	0.017	0.018	0.217				
807	0.034	0.037	0.036	0.434	0.031	0.034	0.033	0.398	0.056	0.056	0.056	0.675
808	0.040	0.042	0.041	0.494	0.032	0.035	0.034	0.410				
809	0.037	0.037	0.037	0.446	0.035	0.037	0.036	0.434				
813	0.045	0.045	0.045	0.542	0.044	0.047	0.046	0.554	0.059	0.059	0.059	0.712
814	0.040	0.043	0.042	0.506								
815	0.045	0.046	0.046	0.554	0.045	0.044	0.045	0.542				
819	0.052	0.052	0.052	0.627	0.042	0.046	0.044	0.530	0.075	0.079	0.077	0.929
820	0.057	0.058	0.058	0.700	0.042	0.042	0.042	0.506				
821	0.062	0.064	0.063	0.760	0.045	0.043	0.044	0.530				

the freezing point was determined. In this test the salt combinations used were with only one amount of monopotassium phosphate, corresponding to 0.4 gm. of the salt per pot. The results are summarized in tables 6 and 7.

Results and discussion

The results of table 6 present several interesting features. Taking the values for the osmotic concentration of the sand treated with a nutrient solution and comparing them with those for the osmotic concentration of the nutrient solution itself, one notices that in most cases the concentration of the nutrient solution increases on its addition to the sea sand. The increase, however, is not the same in all series. Indeed, this value in the 20 per cent series is many times as great as in the 60 or 80 per cent series of the same number of cultures.

The differences in the total osmotic concentrations of these sand cultures with different moisture contents are, of course, even more pronounced.

The corresponding values in table 7, which represent the osmotic concentrations of the solutions in the Sassafras light sandy loam, differ somewhat

from those of the sea sand. The chief differences consist (a) in the fact that, although the osmotic concentration of the nutrient solution in the soil, after adding to it the nutrient solution, increases in the 20 and 40 per cent series, the increase is always less than the osmotic concentration of the original soil when the moisture is brought up to the required content with distilled water. In the 60 and 80 per cent series even the total osmotic concentration becomes less than that of the original nutrient solution, when this nutrient solution is introduced into the soil. (b) The total osmotic concentration of the solution in the soil of the 20 per cent series is considerably higher than in the corresponding series of the sea sand cultures. And, for this reason, the difference between the total osmotic concentration of the soil solution and the original solution is much greater than the corresponding difference in the sea sand.

TABLE 8

Comparison between the osmotic concentration of the nutrient solution and that of the soil solution after adding the nutrient solution to the soil or sand. The values are given in atmospheres

CULTURE NO.	SERIES OF 80 PER CENT		SERIES OF 60 PER CENT		SERIES OF 40 PER CENT		SERIES OF 20 PER CENT	
	Original nutrient solution	Soil solution	Original nutrient solution	Soil solution	Original nutrient solution	Soil solution	Original nutrient solution	Soil solution
				Sassafras light sandy loam				
	atm.	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*	*atm.*
7–3	0.627	0.325	0.748	0.502	1.085	1.896	1.869	8.179
7–9	0.675	0.460	0.832	0.566	1.145	1.857	1.990	8.079
13–15	0.712	0.534	0.868	0.574	1.315	1.962	2.267	8.672
19–21	0.929	0.696	1.254	0.796	1.688	1.970	3.002	9.346
				Sea sand				
1–3	0.518	0.675	0.603	0.868	1.242	1.230	2.014	3.929
7–9	0.627	0.840	0.784	0.989	1.411	1.688	2.267	4.062
13–15	0.784	0.904	0.965	1.507	1.495	1.966	2.688	5.664
19–21	0.965	1.194	1.206	1.494	1.797	2.604	3.401	6.049

To facilitate the study of these variations table 8 is presented in which are given the average values of osmotic concentrations of three cultures that vary only in the amount of application of calcium carbonate. Table 8 enables one to compare these values in the different series. Figure 3 may facilitate the examination and interpretation of the results.

The values in table 8 and figure 3 are expressed in atmospheres of osmotic concentration. Studying this table and diagram one finds that the difference between the nutrient solution and the sand with this solution is very small in the 80 and the 60 per cent series. It increases somewhat in the 40 per cent series, and becomes greatest in the 20 per cent series. The difference is always in favor of the sand. In the soil, on the other hand, in the 80 and 60 per cent series the difference is in favor of the solution, while in the 40 and 20 per cent

series it is again in favor of the soil. The concentration is greatest in the 20 per cent series with the largest application of the ammonium sulfate. Indeed, the osmotic concentration of both the sand and the soil is consistently increased in each of the series with the increase in application of the salt ingredients.

The results discussed in the foregoing paragraphs are due, it seems, to the phenomenon of absorption. The solid particles in the soil or sand have the property of adsorbing both the water and the ions of different salts. The degree of adsorption of the different ions of the various salts fluctuates considerably with the nature of the salt and also of the soil. The water is adsorbed perhaps in direct proportion to the relative internal surface. In the

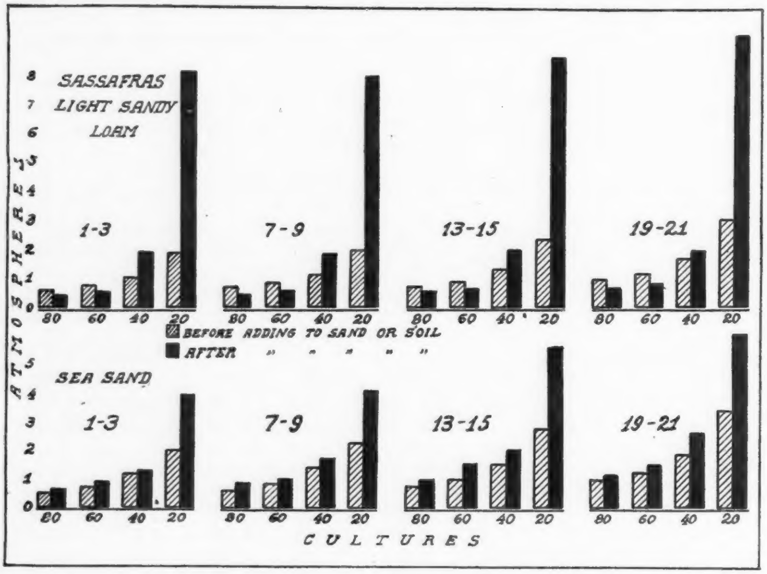

FIG. 3. COMPARISON BETWEEN THE TOTAL OSMOTIC CONCENTRATION OF THE NUTRIENT SOLUTION AND THAT OF THE SOIL OR THE SAND SOLUTION AFTER ADDING THE NUTRIENT SOLUTION TO SOIL OR SAND

The values represent the averages for 3 duplicate cultures of the same manurial treatment (with exception of calcium carbonate); 1–3, 7–9, etc. are the culture numbers; figures 80, 60, 40, and 20 represent the series of cultures kept at these percentages of the water-holding capacity

more inert solid medium, such as sand, the adsorption of salts also takes place perhaps in the proportion to the internal surface of the medium, and in proportion to the substance present in available form for reaction. In the soil, however, this relation is not so simple. There may come into play the absorptive property of the soil, which may influence the reaction very considerably. The chemical reaction, of course, is the final possibility and, undoubt-

edly, accompanies every application of the fertilizer to the soils. In the soil, besides, there may occur what is often called selective adsorption, or selective absorption, depending on the degree of reaction between the two phases. The term selective adsorption can also be applied to sand, if, on the introduction of a salt solution, one of the ions is adsorbed to a greater extent than the other, or if the amount of water adsorbed is greater than that of any of the salt ions.

Examining the values of osmotic concentration in table 8 and studying figure 3, one will notice that the phenomenon of adsorption in the sand and soil will perhaps explain the attitude of the values in different series. In the sand, on the introduction of the nutrient solution to the solid phase, some of the cations of the component salts were adsorbed to a greater extent than the anions, which resulted in the formation of acid or acids. Thus formed, the acid or acids caused an increase in the total osmotic concentration. Such a possibility was discussed in connection with some previous work (266, 267). There was, undoubtedly, some selective adsorption of water, which helped still more to increase the concentration of the resultant solution. In the 80 and 60 per cent series the influence of the adsorbed water was not sufficient to be noticeable with the method here used, because the relative amount of adsorbed water to the total water present was very small. In the 40 and 20 per cent series, however, this influence was very considerable. On reduction of the absolute volume of water, while the power of adsorption remained practically the same, the adsorbed water was, it seems, the dominant factor in modifying the osmotic concentration of the resultant solution.

The considerations presented above explain why the difference between the total osmotic concentration of the solution in the sand and the original solution is so great in every combination of the 20 per cent series.

In the soil the same agencies were at work, only differing in the degree of their action. Although the formation of an acid or acids had taken place, the total adsorption of the salts and of the acids formed in the soil was greater than the increase in concentration caused by enhanced dissociation due to acid formation. This accounts for the decrease of the concentration of the nutrient solution after adding it to the soil in the 80 and 60 per cent series. The relative adsorption of water was not great enough to modify the results considerably. On passing to the soil of the 40 per cent series, one notices that the adsorption of water begins to play a relatively important rôle. The total concentration increases rapidly. In the 20 per cent series the same phenomenon is noticed, only to a much greater degree. The salts present in the original soil, of course, add to the total osmotic concentration of the solution. The main reason for the changing osmotic concentration lies, however, in the fact that some of the water ceases to exist in the free state and the solution becomes much more concentrated. This hypothesis finds ample support in the results of recent investigations of Bouyoucos (27), who reports that some of the water, on being added to air-dry soil, becomes fixed in the latter to such an extent as to fail

to freeze when it is brought to a temperature considerably lower than the freezing point of water. The adsorption of water is greater in heavier than in lighter soils. For this reason, in the heavier types of soil one should expect a still greater osmotic concentration of the resultant solution under the same conditions, as in the 20 per cent series in the present work. In the presence of suitable substances in the soil there may take place an adsorption and also a chemical reaction that would modify the character of the resultant solution, as well as its total osmotic concentration. McCool and Wheeting (149) have found that the latter had taken place to a considerable extent, when certain single salts were introduced into the soil.

The results given in tables 6, 7, and 8 and illustrated in figure 3 throw some light on the data obtained for the growth of plants. Indeed, the values for the osmotic concentration of the series with the different moisture contents are very significant. In the 80 and 60 per cent series the absolute osmotic concentrations are quite low, and the variations are very small. These values range oinly between 0.7 and 1.5 atmospheres in the sea sand of both series. In the soil the variations were even smaller, the osmotic concentration values being here between 0.31 and 0.85 atmospheres. Within these limits the differences in plant production in cultures under different fertilizer treatments could not be attributed to the change in the osmotic, concentration of the nutrient soil solution. On the application of fertilizer in field practice the modification in osmotic concentration will not be very considerable, if the moisture content remains around 60 or 80 per cent of the saturation. If one compares, for instance, the values for the osmotic concentration of cultures 1–3, 7–9, 13–15, and 19–21 of the 80 per cent series for the Sassafras light sandy loam, one will find that on the increase in the application of ammonium sulfate from 0.05 gm. per pot to 0.4 gm. per pot the osmotic concentration increases from 0.325 atmospheres to 0.696 atmospheres, an absolute increase of only 0.371 atmospheres. Assuming a weight of 2,000,000 pounds, 0.4 gm. of ammonium sulfate corresponds to 400 pounds of the salt per acre. By doubling the amount of salt applied one would expect that the increment in the osmotic concentration of the resulting soil solution would not exceed that obtained from the first 0.4 gm. In all probability the increment would be considerably smaller, because of the increased adsorption, and also on account of the decrease in the ionic dissociation. At its maximum the osmotic concentration of a solution in the ordinary agricultural soil would not exceed perhaps 1.0–1.2 atmospheres. This osmotic concentration, it must be admitted, is not very high for the growth of plants. A higher osmotic concentration is often employed by plant physiologists (206, 226) for the best development of plants. In varying the osmotic concentration of the nutrient solution between 0.5 and 3.5 atmospheres McCall (147) finds that 2.0 atmospheres of the osmotic concentration of Shive's (206) nutrient solution, when added to the sand cultures, produces the greatest amount of dry matter of wheat. Since the results of the present work, and also of one published recently (267), show that there is, comparatively speaking, very little change taking place in the osmotic concentration of the nutrient

solution, when it is introduced into the sand at the optimum moisture content, we may ignore the difference for the present. In order to bring the osmotic concentration of our soil solution to, let us say, 2.0 atmospheres we should have to add a considerable amount of the fertilizing material. Yet, the additional amount of 0.4 gm. of ammonium sulfate per pot would bring the total amount of ammonium sulfate in the pot to 0.8 gm., which would correspond to 800 pounds of this salt per acre, an amount hardly ever used in ordinary field practice. Taking the values for the 60 per cent series the results would be somewhat higher; the difference, however, should not be very great.

From the foregoing considerations it would follow, therefore, that under field conditions, if the moisture content remains somewhere around the optimum, the ordinary application of fertilizer would not in any case modify the osmotic concentration of the soil solution to an extent sufficient markedly to affect plant growth. Increased plant production in the present experiment was evidently due to other causes. The more important among them may be (a) the increase in the total amount of plant-food, and (b) the modification in the balance of salts in the soil solution.

The osmotic concentration of the soil solution begins to play a dominant rôle when the water content becomes low. This begins to be noticeable in the 40 per cent series, in which case the osmotic concentration varies between 1.2 and 2.6 atmospheres in sea sand, and between 1.7 and 2.0 atmospheres in the Sassafras light sandy loam.

In the 20 per cent series the effects become very pronounced. The concentration in the sand varied from 3.6 to 6.2 atmospheres, and in the soil, from 7.5 to 9.4 atmospheres. At this moisture content it is a real factor, and, perhaps, is the chief reason why the yield curve of the 20 per cent series is so far below the others in the soil experiment (fig. 2). The values for the osmotic concentration of the cultures in the 40 and 20 per cent series show the importance of maintaining the proper supply of water in the soil, and seem to explain the low efficiency of some fertilizer materials in seasons of low precipitation.

The relation between the total osmotic concentration of the soil solution and plant yield can best be studied from figure 4 in which are plotted the values for the average yield of cultures 19–21, inclusive, of the Sassafras light sandy loam of the different series and also of the average osmotic concentrations for the same cultures. The treatments of cultures 19–21, as shown in table 2, differ only in the amount of calcium carbonate added. An examination of figure 4 shows in a very striking manner the dependence of plant growth on the osmotic concentration of the soil solution as brought about by the difference in the moisture content of the soil. Somewhat similar relations will be observed if parallel studies are made with the other cultures of either the Sassafras soil or the sea sand.

Refering once more to tables 6 and 7, one will notice that the osmotic concentration of the soil solution in the sand and soil was considerably reduced during the 30-day growth of barley. A greater absolute reduction in osmotic

concentration occurred in the series with the smaller moisture content. That is to say the 20 per cent series has lost most heavily, and was followed by the 40, 60, and 80 per cent series, in the order named. Comparing the same series of the two experiments, one finds that the series in the sea sand have lost more heavily, both relatively and absolutely.

EFFECT OF VARIOUS AMOUNTS OF CERTAIN NUTRIENT AND NON-NUTRIENT SALTS ON THE EFFICIENCY OF AMMONIUM SULFATE FOR THE GROWTH OF BARLEY IN SAND CULTURES

As was noticed previously in the vegetation experiments, in both the sea sand and the Sassafras light sandy loam the plants lodged in all cultures, when 0.4 gm. of ammonium sulfate was applied per pot. These cultures corresponded to culture numbers 19 to 24, inclusive. The lodging occurred in every series and, therefore, could not be attributed in every case to the heavy yield. Consulting tables 3 and 5 and figures 1 and 2, one will notice that the yield of the best pots of the 20 per cent series was not nearly as good as in the 40, 60, or 80 per cent series in cultures 13 to 18, inclusive, in which case the plants did not show any tendency to lodge. It is commonly observed in field practice that the plants usually have a tendency to lodge on land rich in available nitrogen. Although the correlation between the excessive supply of available nitrogen and the lodging of plants is very frequently noticed, yet there are times when, in the presence of an apparently excessive content of nitrogenous materials, rigid straw is produced.

Evidently, there are other factors which influence the rigidity of plant tissues. The profound influence of salt proportions on the growth of plants (226, 206, 147, 267) can not be, in seems, without some influence on the quality of their tissues. In view of this deduction it was decided to test different salts in combination with the nutrient solution, which, when present alone in the sea sand or the Sassafras light sandy loam cultures, caused the young plants to lodge.

There was another justification for performing this experiment. Although in the nutrient solution used in the present vegetative experiments there was present every element which is necessary for plant growth (according to the common conception of the subject), yet there is a possibility of increasing plant growth by some other elements or ions or salts, which may in some combinations enhance the growth of plants.

Review of literature

Common salt, sodium chloride, is usually recognized as a good amendment in soil management. Hellriegel (96) found that sodium chloride increased the yield even in the presence of an abundance of potassium. Similar results are reported by Schulze (200). Indeed, in another article the same author (199) recommends the addition of some sodium chloride with each application

of ammonium sulfate, because sodium chloride acts especially favorably with this fertilizer.

In former times calcium sulfate was often used as an amendment with some beneficial results. Yet, its value for this purpose is strongly disputed by Stebutt (213) and also by Soave (208). The latter author, however, finds that calcium sulfate produces a beneficial effect, if it is combined with soluble potash. Takeuchi (223) observed that calcium sulfate produces no beneficial effect with the acidic fertilizers and causes an increase in yield, if used with alkalinic fertilizers. He finds it to be injurious with superphosphate and ammonium sulfate, and beneficial with sodium nitrate.

Sodium silicate is found (236) to be of some benefit to crops when used in connection with green manuring.

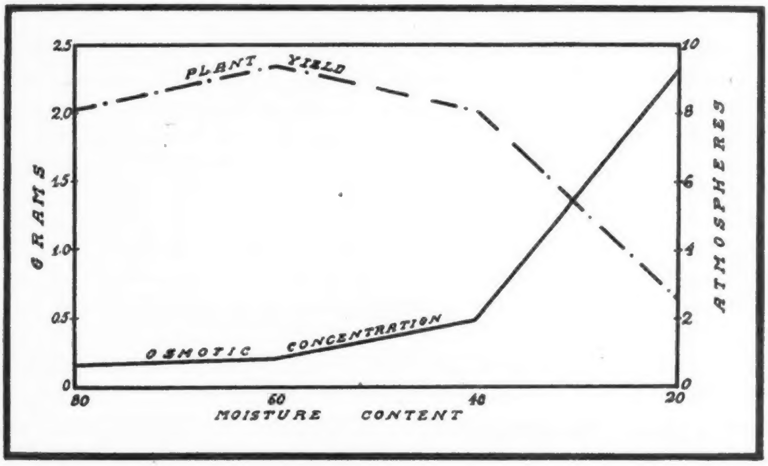

FIG. 4. THE RELATION BETWEEN THE TOTAL OSMOTIC CONCENTRATION OF THE SOIL SOLUTION AND THE PLANT YIELD IN THE SASSAFRAS LIGHT SANDY LOAM

The figures 80, 60, 40, and 20 are the percentages of the water-holding capacity of the soil

In view of the results of the investigations mentioned above and elsewhere it seemed possible that some of the substances may favorably influence the nutrient solution of the formula adopted in the present work.

Procedure

Of the two media used in previous experiments the sea sand contained the less plant-food, which was evident from the growth of barley in the untreated pots. In order better to interpret the results of the experiment, as to the influence of different salts upon the growth and development of plants, sea sand was used as the medium in this experiment. The same pots, holding 2 kgm.

of sand, were again employed. The following salts were used in addition to the formula of culture 24 (see table 2), which culture consisted of 0.4 gm. ammonium sulfate, 0.8 gm. monopotassium phosphate, 0.2 gm. magnesium sulfate, 0.05 gm. ferrous sulfate, and 2.0 gm. calcium carbonate per pot: increasing amounts of magnesium sulfate, monopotassium phosphate, and ferrous sulfate, and also different amounts of potassium chloride, sodium chloride, sodium nitrate, calcium sulfate, aluminum sulfate and sodium silicate, increasing at a uniform rate. For comparison, a culture with sodium nitrate as the source of nitrogen was employed. The ingredients used in each pot were as follows: 0.5 gm. sodium nitrate, 0.8 gm. monopotassium phosphate, 0.2 gm. magnesium sulfate, 0.05 gm. ferrous sulfate, and 2.0 gm. calcium carbonate. Table 9 gives the formula for each culture in actual application per pot, and also the calculated values for an acre 6 inches of soil (2,000,000 pounds was used for calculation).

The moisture content was kept at about 60 per cent of the water-holding capacity of the sand. The water was added daily, the pots being weighed every other day. The seeds were planted in the pots; when germinated, the seedlings were thinned to 8 for each pot. The surface of the sand was left uncovered. Thus, the evaporation of the water from the surface of the sand and the transpiration of water by the plants was taken as the total loss of water. After a 30-day growth from the time of thinning, the plants were harvested, dried and weighed. The dry weight, together with the water requirement of the plants grown in different nutrient solutions in the sand medium, are given in table 10. The same table also gives the values for the degree of stiffness of the straw. The observations to this effect were made on the day of harvesting. To represent the rigidity of the straw an arbitrary sign of small crosses was adopted. One cross (+) was taken to represent that the plants were lodged badly. Three crosses (+++) were taken to indicate that the plants stood erect, while two (++) crosses indicate medium stiffness of the straw.

In order to facilitate the examination of table 10, figure 5 is given in which the cultures with the same salts are grouped together and the results are contrasted with culture 4, or the one which received no additional salts outside of those which contained only the necessary elements. The curve for the water requirement of the plants is given in the upper portion of the diagram.

Results and Discussion

A careful examination of table 10 and figure 5 reveals the striking influence of some of the salts on the fertilizing value of the nutrient solution composed of ammonium sulfate, monopotassium sulfate, magnesium sulfate, ferrous sulfate and calcium carbonate. On addition of some of the salts to the sand cultures there was a remarkably large increase in total yield of dry matter, when this addition was made in moderate quantities. In most cases, however,

TABLE 9

Application of salts per pot containing 2 kgm. of sea sand, and the calculated values in pounds per acre

CULTURE NO.	$(NH_4)_2SO_4$		$CaCO_3$		KH_2PO_4		$MgSO_4$		$FeSO_4.7H_2O$		KCl		NaCl		$NaNO_3$		$CaSO_4$		$Al_2(SO_4)_3$		Na_2SiO_3	
	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre	Per pot	Per acre
	gm.	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*	*gm.*	*lbs.*
1																						
2	0.2	200	2.0	2,000	0.4	400	0.2	200	0.05	50												
3	0.4	400	2.0	2,000	0.4	400	0.2	200	0.05	50												
4	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50												
5	0.4	400	2.0	2,000	1.2	1200	0.2	200	0.05	50												
6	0.4	400	2.0	2,000	1.6	1600	0.2	200	0.05	50												
7	0.4	400	2.0	2,000	0.8	800	0.4	400	0.05	50												
8	0.4	400	2.0	2,000	0.8	800	0.6	600	0.05	50												
9	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50	0.1	100										
10	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50	0.2	200										
11	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50	0.4	400										
12	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50			0.1	100								
13	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50			0.2	200								
14	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50			0.4	400								
15	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50					0.1	100						
16	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50					0.2	200						
17	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50					0.4	400						
18	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50							0.2	200				
19	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50							0.4	400				
20	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50							0.8	800				
21	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50									0.1	100		
22	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50									0.2	200		
23	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50									0.4	400		
24	0.4	400	2.0	2,000	0.8	800	0.2	200	0.10	100												
25	0.4	400	2.0	2,000	0.8	800	0.2	200	0.20	200												
26	0.4	400	2.0	2,000	0.8	800	0.2	200	0.40	400												
27	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50											0.1	100
28	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50											0.2	020
29	0.4	400	2.0	2,000	0.8	800	0.2	200	0.05	50											0.4	400
30	0.6	600	2.0	2,000	0.8	800	0.2	200	0.05	50												
31			2.0	2,000	0.8	800	0.2	200	0.05	50					0.5	500						

the yield reached a maximum with the quantities applied and then began to decline.

On account of differences in the influence of the different salts, it is well to consider them separately in the brief discussion of the results.

With the increase in the quantities of monopotassium phosphate (cultures 3, 4, 5 and 6) there was a slight increase in dry weight up to 0.8 gm. of the salt applied. Then some decrease resulted. With the largest application (1.6 gm.

of the salt per pot) of the phosphate the yield was even lower than with the smallest application. The results obtained with this salt could not be compared with those from other salts on an equal basis because the quantities of salts applied were different. Yet, there were evidently similar effects from monopotassium phosphate and some of the other salts.

Certain quantities of magnesium sulfate had a greater influence on the increase in plant growth than the salt discussed above.

The same thing can be said of potassium chloride, although the maximum beneficial effect in this case was passed, and was somewhere between 0.2 and 0.4 gm. of the salt per pot.

The results with sodium choride were quite in accord with those of potassium chloride, although the yield of the culture with 0.2 gm. of sodium chloride (no. 13) was the greatest in the whole series.

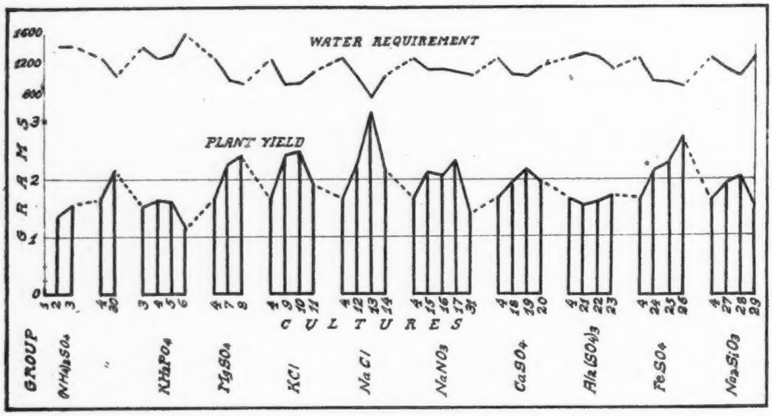

Fig. 5. The Effect of Different Amounts of Various Salts on the Manurial Value of Ammonium Sulfate in Sea Sand Cultures, and the Relation of Plant Yield to the Water Requirement of Plants

It is intersting to note that potassium in monopotassium phosphate is present in abundance to satisfy the plant needs, yet the addition of more potassium in the form of chloride caused a considerable increase in the dry matter produced.

In the sodium chloride group there was no addition of any element that is considered essential for plant growth; nevertheless, the stimulus due to sodium chloride, in a certain combination, led to the most luxuriant growth. This could be ascribed either to the influence of sodium, of chlorine or of the combination of the two in the proper balance with other salts in the nutrient solution in the sand cultures.

The use of nitrogen in sodium nitrate, was accompanied by an increase in plant growth ($NaNO_3$) group. Either ammonium sulfate or sodium nitrate

alone gave a lower yield than the mixture of these two salts. It may be noted that 0.4 gm. of ammonium sulfate was more efficient than 0.5 gm. of sodium

TABLE 10

The dry weight of barley, the water requirement of plants, and the rigidity of the straw, as influenced by different salts in the nutrient solution in sea sand cultures; the growing period is 30 days

CULTURE NO.	YIELD OF DRY MATTER			TOTAL WATER LOSS			WATER REQUIREMENTS	RIGIDITY OF STRAW
	1	2	Average	1	2	Average	Average	Average
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	
1	0.1290	0.1190	0.1240	1,086	1,081	1,084	8,742	
2	1.3515	1.3980	1.3748	1,974	1,958	1,966	1,430	+*
3	1.6955	1.3685	1.5320	2,160	2,206	2,183	1,425	+
4	1.5985	1.7410	1.6698	2,194	2,051	2,123	1,271	+
5	1.5630	1.6605	1.6118	2,044	2,182	2,113	1,311	++
6	1.1140	1.1400	1.1270	1,836	1,804	1,820	1,615	+
7	2.6650	1.8365	2.2508	2,255	2,021	2,138	950	++
8	2.5185	2.8065	2.6625	2,158	2,253	2,206	903	+++
9	2.8600	1.9605	2.4103	2,175	2,154	2,165	899	+++
10	2.7425	2.1955	2.4690	2,380	2,147	2,264	916	+++
11	1.6155	2.1865	1.9010	2,046	2,121	2,034	1,071	++
12	2.0705	2.3755	2.2230	2,291	2,183	2,237	1,007	++
13	2.9225	3.3825	3.1525	2,332	2,288	2,310	732	+++
14	1.9885	2.2935	2.1410	2,149	2,161	2,155	1,007	++
15	2.2865	1.9615	2.1240	2,495	2,238	2,367	1,115	+
16	1.8295	2.3175	2.0735	2,347	2,489	2,418	1,166	+
17	2.2735	2.3795	2.3265	2,549	2,436	2,493	1,072	+
18	1.8525	2.0235	1.9380	2,090	1,858	1,974	1,019	++
19	2.2885	2.0595	2.1740	2,236	2,136	2,186	1,006	++
20	1.8905	1.9705	1.9305	2,214	2,254	2,234	1,159	++
21	1.6695	1.4220	1.5458	2,110	1,992	2,051	1,324	+
22	1.7985	1.4155	1.6070	2,100	2,012	2,056	1,280	+
23	1.7980	1.6385	1.7183	1,963	1,899	1,931	1,124	+
24	1.8955	2.4255	2.1655	1,957	2,086	2,022	936	++
25	2.1595	2.3910	2.2753	2,087	2,164	2,126	935	++
26	2.9815	2.5125	2.7470	2,253	2,396	2,325	846	+++
27	1.6115	2.2385	1.9250	2,119	2,221	2,170	1,127	++
28	2.2585	1.9095	2.0840	2,174	2,062	2,118	1,016	++
29	1.4665	1.5475	1.5070	1,935	1,920	1,928	1,279	+
30	1.7970	2.5740	2.1855	2,142	2,285	2,214	1,013	++
31	1.3255	1.4485	1.3870	2,147	2,352	2,250	1,622	+

* The sign of one cross (+) indicates that the plants were badly lodged; the sign of three crosses (+++) that the plants were standing erect; and the sign of two crosses (++) that the plants had straw of medium rigidity.

nitrate (see no. 4 and 31 in the sodium nitrate group, figure 5) and, therefore, nitrate of soda under these conditions was apparently benefited by the addition of ammonium sulfate more than ammonium sulfate was benefited by the addition of sodium nitrate.

The calcium sulfate group shows itself to be very similar to the potassium chloride group. Calcium in one case and potassium in another were introduced in addition to the plentiful supply of these elements in their respective cultures. The difference between these two groups consists in the fact that in the potassium chloride group there was a new ion and even element, namely, chlorine, while in the calcium sulfate group this was not the case. Both the calcium and the sulfate ions were present in some of the salts. Yet, the addition of these ions in different combination and their influence on the modification of the resultant nutrient solution was accompanied by some increase in plant growth.

An increased application of ferrous sulfate caused an increase in the production of dry matter, the largest growth having occurred with the largest application (0.4 gm).

Sodium silicate also caused an increase, when added in small amounts. There was some decrease noticed, when the application was at the rate of 0.4 gm. per pot.

Aluminum sulfate was singular in its behavior. Its effect, if there was any, was rather negative in character. There was a depressive effect with the smallest application.

Finally, with the increase in ammonium sulfate from 0.4 to 0.6 gm. per pot containing 0.8 gm. of monopotassium phosphate (pots 4 and 30) the increase in yield was greater than that from an ammonium sulfate increment ranging from 0.2 to 0.4 gm. per pot containing 0.4 gm. of monopotassium phosphate.

The nature of the results presented in table 10 and figure 5, it seems, would warrant the following general deduction. The formation of small amounts of sulfates of magnesium, calcium or iron would benefit the growth of plants like barley, if it is accompanied by the application of fertilizer represented by ammonium sulfate, superphosphate and a liberal amount of lime. The formation of these salts is possible out of the previously applied ammonium sulfate, due to the intake of the ammonium ion by plants and the leaving of some of the sulfate ion behind. The latter ion, not being able to exist as such, forms sulfuric acid, which combines with the most available bases forming sulfates. Thus, calcium, magnesium, iron and aluminum sulfates may be formed, perhaps in the order named. That is to say, if the soil contains an abundant supply of lime, some calcium sulfate will be formed, thus slightly benefiting the plant growth. In the absence of calcium carbonate some other carbonates would be used. If aluminum compounds are the most available of the bases present, the results may be entirely different. An injurious instead of a beneficial effect may be observed in that case.

On the whole, a moderate increase in the sulfate formation of certain bases in some soils, would, therefore be of considerable benefit to the crops. The increase in the growth of barley as noticed in the cultures under different salt treatments may be attributed to the modification in the balance of the component salts that go to make the soil solution. It would hardly be possible

that such an increase was caused by the increase in the osmotic concentration of the soil solution. This fact, it seems, was disclosed by the vegetation experiments described in the first part of this paper. The osmotic concentration, per se, could hardly be expected to play a very important role with these applications of the salts, unless the moisture content of the medium (sand in this case) is reduced to, or below, 40 per cent of the water-holding capacity of the medium.

The rigidity of the straw, or the ability of the plants to stand more or less erect during the first stage of growth, is another feature which was observed in connection with this experiment. An examination of the values for the stiffness of straw in table 10 shows that there is a considerable variation in the ability of plants of different cultures to stand erect. The lodging effect of the nutrient solution of culture 4 (table 10) was completely overcome by the addition of certain amounts of magnesium sulfate (no. 8), small quantities of potassium chloride (no. 9 and 10), sodium chloride (no. 13), or iron (no. 26). A considerable improvement in this direction was noticed in other cultures on the addition of small amounts of other salts.

The plants that lodged badly did not correspond with those of the heaviest yield. Indeed, the reverse tendency is noticed in the values obtained in this experiment.

Considering this feature from another point of view, the improvement of the nutrient solution of culture 4 (table 10) on the addition of some salts, such as chlorides of potassium and sodium, and sulfates of magnesium and iron, was accompanied by an increase in both plant growth and rigidity of straw. It is justifiable, therefore, to conclude that the stiffness of the straw is modified not by the presence of a definite quantity of some one element in the soil solution, but by the combination of different ingredients which constitute the soil solution. A proper balance of the salts in the nutrient solution is just as necessary for the rigidity of the straw as for the plant yield.

There is another feature which may be mentioned in connection with this experiment. A glance at the curves of figure 5 will reveal a pronounced reciprocal relation between the total yield of tops and the water requirement of plants (or the grams of water used for the growth of one gram of dry matter). In nearly every case the increase in yield was followed by a decrease in the water requirement, and vice versa. The values, on the whole, agree with those obtained in the previous experiment with sea sand kept at the same moisture content.

EFFECT OF MOISTURE CONTENT ON THE GERMINATION OF BARLEY SEEDS IN SAND AND DIFFERENT SOILS

Introduction

In the experiments on growing plants of barley in sand and soil with different moisture contents and different fertilizer treatments, the germination of seeds was allowed to take place either under very uniform conditions (sea sand ex-

periment), or under the influence of different fertilizer treatments, while the moisture content of the soil remained the same (Sassafras light sandy soil experiment). In both cases the influence of different moisture contents was eliminated as much as possible. However, since the moisture content is a very important factor in modifying the growth and development of plants, it seemed advisable to test the germination under the same conditions of moisture, under which the growth of plants had occurred.

Review of Literature

The influence of moisture content upon the germinating power of seeds has been the subject of much study. Goff (74) has observed that an excess of water, excluding the soil air, is detrimental to the germination of beet seeds. Coulter (48) made an extended study of the effect of temperature and moisture changes on the germination of seeds of different plants. As a result of his study of temperature and humidity in their relation to the germination of seeds of different grasses, Deneumostier (54) finds that different grasses require different moisture contents for optimum germination. Rye grasses, meadow fescue and tall oat grass did best when the germinating bed was kept at not less than 60 per cent of saturation, while timothy, crested dog's tail and velvet grass were injured by such moisture content. For the best germination of these the moisture content should in no case exceed 60 per cent of saturation. Livingston (139) obtained similar results. Studying *Fouquieria splendeus*, giant cactus, Mexican bean, wheat, balsam, radishes and red clover, he found that these seeds had different minimum water requirements for their germination, the variations being from 15 to 25 per cent of water of the soil studied. As a rule a somewhat better germination took place at a somewhat higher moisture content than at a minimum content.

The effect of different fertilizers and salts was also studied by a number of investigators.

De Marneffe (142) observed some differences in seed germination due to the application of fertilizers. In 1 per cent concentration, potassium sulfate and nitrate of soda were found by Hicks (99) to be detrimental to wheat, lettuce, radish and crimson clover. Phosphoric acid and lime were much less injurious in such concentrations. In an extensive study, Rusche (185) reports that when he kept his soil at 70 per cent of saturation, the application of small amounts of chlorides, nitrates, sulfates, carbonates and phosphates acted differently on the germination of seeds of the same plant. Some of the salts were injurious, others were beneficial, while the rest of them did not influence the germination to any great extent. He studied seeds of many agricultural plants and found that different crops responded differently to the fertilizer treatment.

Claudel and Crochetell (43) have found that at lower concentrations, ammonium sulfate, sodium nitrate, lime, etc. did not cause any injury in germination, but above 0.2 per cent both ammonium sulfate and sodium nitrate

resulted in injury to the seedlings. Nitrate of soda at the rate of 265 pounds per acre retarded but did not prevent germination, according to von Feilitzen (59). De Chalmont (40) also reports that a high concentration of nitrates retards the germination of seeds in water cultures or in powdered pumice stone, while in dilute solutions they favor germination. Common salt, if present in high concentrations, is injurious to the germination of seeds, as reported by Ewart (58) and Haselhoff (92). Lime was found to increase the germinating power of a number of flower plants (31).

The reports on the effect of acids upon the germination of seeds are rather conflicting. Thus, Claudel and Crochetell (43) and Tolf (225) find that acids are injurious to germination, while Promsy (176a, 176b) reports that both organic and inorganic acids in dilute solutions favor germination.

Green manuring also may be injurious to the germination of seeds under certain conditions (62, 63, 102).

I. *Germination study in sand cultures under different fertilizer treatments*

Procedure

The first part of the germination tests of the present work was carried out in sea sand. For this purpose 300 gm. of sea sand was weighed out and placed in tumblers. The sand was supplied with exactly the same proportions of fertilizing materials and moisture as in the corresponding vegetation experiments with the same material. Ten selected barley seeds were placed about half an inch deep in the moist and compacted sand of each tumbler, the surface of the sand was again slightly compacted, and the tumblers were covered with squares of glass. This was done to prevent evaporation of water from the surface. On the seventh day from seeding the germinated seedlings were counted in each tumbler. The results are given in table 11, which show the number of seeds germinated in the cultures of each of the four series. The 20, 40, 60 and 80 per cent series contained 4.86, 9.72, 14.58, and 19.44 per cent of water, respectively, as based on the air-dry sand, whose water-holding capacity was equal to 24.3 per cent. Each series consisted of 54 tumblers.

Results and discussion

Table 11 reveals a remarkable fact. It not merely shows that the moisture content equivalent to 40 per cent of the water-holding capacity did not retard the germination, but that the moisture content equivalent to 20 per cent of the saturation was sufficient for nearly a perfect stand. The germination was strikingly uniform in all the series, the seeds of the 20 per cent series came through about 24 hours later than those in the remaining series. Only in a few tumblers, namely, in numbers 19 to 23, inclusive, of the 20 per cent series, were the seedlings more or less retarded. There were also two sets in the 40 per cent series that were somewhat behind in their coming through the sand.

Shive's (206) nutrient solution in both the 20 and 40 per cent series showed some retardation, this being more pronounced in the 20 than in the 40 per cent series. With these few exceptions there was apparently no injurious effect of the fertilizing salts applied in any combination.

TABLE 11

Number of barley seeds germinated in sea sand cultures under different fertilizer treatments in four different moisture contents, 10 seeds being planted

SERIES...	20		40		60		80	
Per cent of H_2O in sea sand	4.86		9.72		14.58		19.44	
Trial.....	1	2	1	2	1	2	1	2
No.								
0	9	10	10	9	10	9	9*	10*
1	10	10	10	10	10	10	10	10
2	10	10	10	10	10	10	10	10
3	10	10	10	10	10	10	10	10
4	8	10	10	10	10	10	10	10
5	10	10	10	10	10	10	10	10
6	10	10	10	10	10	9	10	10
7	10	10	10	10	10	10	10	10
8	10	10	10	10*	10	10	10	10
9	9	10	10	10	10	10	10	10
10	10	10	10	9	10	10	10	10
11	10	10	10	10	10	9	10	9
12	10	10	10	10	10	10	10	9
13	10	10	10	10	10	10	10	10
14	10	10	10	10	10	10	10	10
15	10	10	10	10	10	9	10	10
16	10	10	10	10	10	10	10	10
17	9	10	9	10	9	10	10	10
18	10	10	10	10	9	10	10	10
19	10*	10*	10	10	9	10	10	10
20	9*	10*	10	10	10	10	10	10
21	9*	10	10	10	10	10	10	10
22	10*	9*	10*	10*	10	10	10	10
23	10*	10*	10*	10*	10	10	10	10
24	10	10	10	10	10	10	10	10
L‡	10	10	10	9	9	10	10	10
S‡	8†	9†	10*	10*	10	10	9	10

* Germination slightly retarded.

† Germination considerably retarded.

‡ L—Lipman's; S—Shive's.

In view of the osmotic concentration values presented in table 6 and also in view of the growth of plants in sand with different moisture contents, the results of the germination test are rather interesting. The germination of seeds is evidently not affected by differences in the moisture content of the

sand to the same extent, as is the growth of plants. It seems that for the initial development of the embryo very little available water is required, and that this water can be obtained from nutrient solutions of very high osmotic concentration. By consulting table 6 one will observe that the osmotic concentration of the nutrient solutions in the sea sand of the 20 per cent series varies from 3.6 to 6.2 atmospheres. This, of course, is considerable, but, it seems, that such osmotic concentration does not prevent the seeds from obtaining the water for their hydration from the thin films surrounding the sand particles.

II. *Germination study in different types of agricultural soils*

Procedure

The results obtained with the sea sand naturally raise the question, whether different types of agricultural soils would permit the seeds to germinate under identical moisture conditions.

In order to throw some light on this question, other germination tests were made. For this purpose, the following soils, together with sea sand, were used: Sassafras light sandy loam, Sassafras medium silt loam, Elkton clay loam, and muck. Muck was procured from the fields of the Alphano Humus Company,[2] while the remaining soils were obtained from the fields of the New Jersey State Agricultural College and Experiment Stations at New Brunswick. The hygroscopic water of the air-dry soil and sand, as well as their water-holding capacity, are given in table 12. In this experiment 250 gm. of soil and 150 gm. of muck were used in the tumblers. One half of the tumblers remained untreated, while the other half received a nutrient solution corresponding to the formula of no. 15 in the vegetation experiments (table 2). The moisture content of each soil varied from 10 to 80 per cent of its water-holding capacity, as based on the air-dry soil. The actual moisture content of each series, that is, the hygroscopic water plus the water added to the soil, is given in table 13.

TABLE 12

Water-holding capacity of different soils, as based on air-dry soil, and the hygroscopic moisture of these soils

SOIL	HYGROSCOPIC MOISTURE OF THE AIR-DRY SOILS			WATER-HOLDING CAPACITY (FUNNEL METHOD)		
	1	2	Average	1	2	Average
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Sea sand	0.054	0.054	0.054	24.2	24.5	24.35
Sassafras light sandy loam	0.94	0.94	0.94	27.7	27.8	27.75
Sassafras medium silty loam	1.72	1.71	1.72	51.9	53.0	52.45
Elkton clay loam	1.82	1.80	1.81	40.8	41.3	41.1
Muck	26.19	25.79	25.99	143.6	144.0	143.8*

* By Hilgard method average of two determination = 143.3 per cent.

[2] The author is indebted to Dr. H. Clay Lint for his kindness in supplying the muck soil.

Figure 6 shows the number of seeds germinated in 10 days after the planting. To complete the curve for the results with the sea sand the figures for the 40, 60 and 80 per cent series were taken from the first experiment on germination (table 11). The curves represent the values for the untreated sand or soils.

TABLE 13

Actual moisture contents of different soils of the various series in the germination experiment (Water added plus the hygroscopic moisture)

SERIES	SEA SAND	SASSAFRAS LIGHT SANDY LOAM	SASSAFRAS FINE SILTY LOAM	ELKTON CLAY LOAM	MUCK
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
10	2.48	3.71	7.47	5.92	40.37
15	3.70	5.09	10.35	7.98	47.56
20	4.91	6.48	13.22	10.03	54.75
40	9.77	12.02	24.72	18.25	83.51
60	14.63	17.56	36.22	26.47	112.27
80	19.49	23.10	47.72	34.69	141.03

TABLE 14

Number of barley seeds germinated in 5 and 10 days after planting in different soils kept at different moisture contents

SERIES	10		15		20		40		60		80	
Number of days after planting	5	10	5	10	5	10	5	10	5	10	5	10
Sea sand												
Untreated	3	9	10	10	10	10						
Untreated	4	10	10	10	10	10						
Treated	3	9	9	10	10	10						
Treated	3	9	8	10	10	10						
Sassafras light sandy loam												
Untreated	0	0	0	0	0	5	10	10	5	5	5	5
Untreated	0	0	0	0	0	6	8	10	7	7	2	2
Treated	0	0	0	0	0	2	10	10	9	9	3	3
Treated	0	0	0	0	0	3	10	10	3	3	2	2
Sassafras medium silt loam												
Untreated	0	0	0	0	3	9	10	10	3	3	1	1
Untreated	0	0	0	1	2	9	10	10	4	4	2	2
Treated	0	0	0	0	2	10	10	10	1	1	0	0
Treated	0	0	0	0	3	9	10	10	2	2	0	0
Elkton clay loam												
Untreated	0	0	0	0	0	0	9	9	9	9	1	1
Untreated	0	0	0	0	0	0	7	8	6	6	0	0
Treated	0	0	0	0	0	0	9	9	7	7	4	4
Treated	0	0	0	0	0	0	8	10	7	7	1	1
Muck												
Untreated	0	0	0	0	0	0	9	9	10	10	6	8
Untreated	0	0	0	0	0	0	9	10	10	10	6	7
Treated	0	0	0	0	0	0	10	10	10	10	9	9
Treated	0	0	0	0	0	0	10	10	10	10	7	8

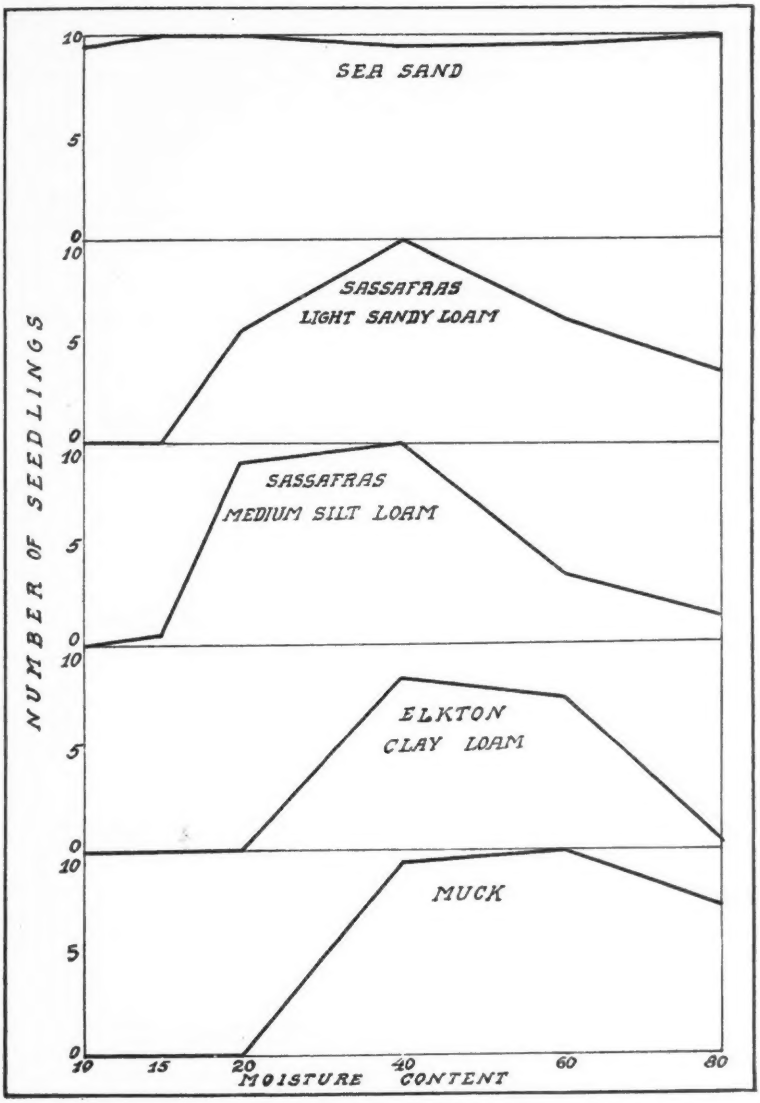

FIG. 6. THE EFFECT OF THE MOISTURE CONTENTS OF DIFFERENT SOILS AND SANDS ON THE GERMINATION OF BARLEY SEEDS

Results and discussion

The results given in table 14 and illustrated in figure 6 show very clearly that the soils differ considerably from the sand in their behavior toward moisture.

In the sea sand a nearly perfect germination was obtained with any moisture content studied, which varied from 2.48 to 19.49 per cent as based on the dry sand. In the soils, however, the curves for germination are entirely different. There was no germination in any of the soils at 10 or even 15 per cent of the water-holding capacity. In the clay and muck soils there was no germination even at 20 per cent of saturation. In both Sassafras soils a considerable germination took place at 20 per cent of the saturation, and the maximum germination was at 40 per cent. Indeed, in every soil the moisture equivalent to 40 per cent of the water-holding capacity was either the best or nearly the best for the optimum germination of barley seeds. Sixty per cent of the saturation for most of the soils was not so good as 40 per cent. In all soils without exception the moisture equivalent to 80 per cent of the saturation was very far from the optimum for the germination of the seeds.

On the whole, the sand has a much greater range in moisture for good germination of barley seeds, while in the different soils studied the range is considerably narrower. In soils with the low moisture content the failure of seeds to germinate was due, partially perhaps, to the high osmotic concentration. But the dominant factor, it seems, was the lack of a sufficient amount of free water around the seeds. That water had been taken in by the seeds was evident from the fact that, after 10 days from planting the barley, in 20 and even 15 per cent of the water-holding capacity (in several cases, in 10 per cent, as well) the seeds examined were swollen considerably. But there was not enough of the free water to start the embryo cells to multiply. On account of the internal friction the movement of water in soils is slower than in sand. In different soils the rate of the movement of water decreases with the increase in the per cent of the fine material, and the movement of the moisture in the same soil decreases with the decrease beyond certain limits in the moisture content. Besides, at the same degree of saturation the per cent of free water is undoubtedly different in different types of soil. These facts account for the variations in the behavior of the sand and soils in the present experiment.

The failure of the seeds to germinate normally in the soils having a moisture content 80 per cent of the saturation is possibly due to the poor aeration and the lack of oxygen for the metabolism of the seed tissue.

The treatment of the soils or the sand with the nutrient solution had a very limited effect, if any, on the ability of seeds to germinate. The salts used would correspond to but a normal application in farm practice. Based on pounds per acre of 2,000,000 pounds in soils and 1,000,000 pounds in muck, the application of salts would equal to 2,000 pounds of calcium carbonate, 200 pounds of ammonium sulfate, 400 pounds of monopotassium phosphate, 200 pounds of magnesium sulfate and 50 pounds of ferrous sulfate. It seems, therefore, that

a normal application of fertilizers, if these fertilizers are well incorporated in the soil, does not have any injurious effect on the germination of the seeds in question. If the fertilizer is applied in drills at the time of seeding, the soil solution immediately surrounding the seeds may become very concentrated, and, consequently, an injurious effect on seed germination may be expected. Any drought prevailing during the germination period, may still further aggravate the situation brought about by the fertilizer treatment.

SUMMARY

The experimental work described above deals with the effect of ammonium sulfate, as used in different combinations with other salts, on the germination and the growth of barley in sand and soil cultures with different moisture contents. The fertilizer treatment consisted of ammonium sulfate, monopotassium phosphate, calcium carbonate, magnesium sulfate and ferrous sulfate in different proportions. The effect of different amounts of potassium chloride, sodium chloride, sodium nitrate, calcium sulfate, aluminum sulfate, and sodium silicate on the main formula of the fertilizing treatment also was studied. The osmotic concentration of the nutrient solutions in many cases was determined both before and after the application of these solutions to the sea sand or the Sassafras light sandy loam, in which the plants were grown. The moisture content was kept more or less constant by adding water daily and weighing the pots every other day, each time bringing the moisture content to the original. The moisture of the pot cultures was kept at four different percentages: 20, 40, 60 and 80 per cent of the water-holding capacity of the sand or the soil studied. In the germination experiment, besides the four variations mentioned above, moisture contents of 10 and 15 per cent of the water-holding capacity also were included.

The results obtained in these studies may be summarized as follows:

1. The moisture content of the soil has a very marked influence on the growth and the development of plants. In the sand cultures the plant yield increases on the increase in moisture content from 20 to 80 per cent of the water-holding capacity of the sand. In the Sassafras light sandy loam the plant yield increases with the increase in moisture content up to 60 per cent of the water-holding capacity of the soil, while the further increase in moisture brought a considerable decrease in the yield of dry matter of barley. The plant growth in the soil or sand kept at a moisture content equivalent to 20 per cent of saturation was very small, and without any direct relation to the water present, as compared with the series of the higher moisture content.

2. With a constant moisture content in the sand, the plant yields increased with the increase in the application of ammonium sulfate, calcuim carbonate, or monopotassium phosphate. The response in the plant growth to the applications of these salts in the amounts used was in the order named. In the Sassafras light sandy loam a similar response to applications of nitrogen was noticed, but not to those of lime, and very little to those of phosphorus.

3. The difference in plant growth in the various moisture contents was attributed to the two factors, the total plant-food remaining the same: (a) the difference in concentration of the soil solution, and (b) the aeration of the soil.

4. The osmotic concentration of the soil solution increases with the decrease in the moisture content of sand or soil, but the changes are not proportional to one another.

5. The change in the osmotic concentration of the soil solution with the change in water content from one series to another was greater than the change in the osmotic concentration of the soil solution due to the different fertilizer treatments, if the water content remained the same.

6. In cultures with the moisture content corresponding to 80 and 60 per cent of the water-holding capacity, the osmotic concentration of the soil solution varied between 0.7 and 1.5 atmospheres in sea sand, and between 0.31 and 0.85 atmosphere in Sassafras light sandy loam. With a moisture content corresponding to 40 per cent of the water-holding capacity the corresponding values for sand were 1.2 and 2.6 atmospheres, and for soil, 1.7 and 2.0 atmospheres. With 20 per cent of the water-holding capacity the maximum and the minimum values in sand were 3.6 and 6.2 atmospheres, respectively, and in soil, 7.5 and 9.4 atmospheres.

7. The osmotic concentration of the soil solution following the normal application of a fertilizer is not great enough to influence plant growth, if the moisture content of the soil is at its optimum (about 60 per cent of saturation). It becomes an important factor only when the moisture content of the soil is considerably reduced (to 40 per cent of the saturation, or lower).

8. On adding the nutrient solution to the soil its osmotic concentration decreases, as measured by the cryoscopic method, if the moisture content of the soil is maintained at 60 or 80 per cent of its water-holding capacity. In the 40 and 20 per cent series of the water-holding capacity the osmotic concentration of the soil solution after the addition of the nutrient solution was greater than that of the nutrient solution itself. By adding the nutrient solution to the sea sand at any of these four moisture contents its osmotic concentration increased. The latter phenomenon was attributed to the formation of acid or acids with the high moisture content, and to the formation of acid or acids and the adsorption of water with the low moisture content. The adsorptive and the absorptive capacity of the soil for salts prevented the effect of these two agencies from becoming noticeable in the change of the osmotic concentration of the soil solution in the Sassafras light sandy loam with 60 and 80 per cent of the water-holding capacity.

9. The osmotic concentration of the soil solution at the end of the growing period (30 days) was smaller than at the beginning of the experiment. The decrease was greater in the sand than in the soil, and also in the lower moisture content than in the higher moisture content of either the sand or the soil.

10. The nutrient solution consisting of 0.4 gm. ammonium sulfate, 0.8 gm. monopotassium phosphate, 2.0 gm. calcium carbonate, 0.2 gm. magnesium

sulfate, and 0.05 gm. ferrous sulfate per 2 kgm. of sea sand cultures with a moisture content equivalent to 60 per cent of the water-holding capacity was benefited by the additional application of magnesium sulfate and ferrous sulfate, and also by small applications of potassium chloride, sodium chloride, sodium nitrate, calcium sulfate, and sodium silicate. The beneficial effect of these salts on plant growth was attributed to the improvement in the balance of the ions of the component salts in the resultant soil solution. Aluminum sulfate under similar conditions had caused some injury to plants.

11. The rigidity of the straw of plants was modified by different salts added to the nutrient solution. A proper balance in the nutrient solution is essential for the rigidity of the straw. The lodging effect of the large amount of nitrogenous material may be entirely subdued by modifying the proportions between the component salts in the nutritive solution in sand cultures.

12. When the evaporation of water from the surface of the sand or of the soil was taken together with the transpiration of water by plants, it was found that the water requirement of plants diminishes with the increase in plant yield, and vice versa.

13. The use of water by plants in Sassafras light sandy loam is most economical with a moisture content equivalent to 40 per cent of the water-holding capacity, and is followed by that of 60 and 80 per cent in the order named.

14. If plant-food is the limiting factor in either soil or sand, the variations in the moisture content do not affect the plant growth.

15. The germination of seeds of barley is influenced by the same general agencies that affect the growth of plants, although not to the same extent. The germination in the sea sand takes place even when the moisture content is reduced to 10 per cent of the water-holding capacity (2.48 per cent based on the dry sand), or when it is raised to 80 per cent of saturation (19.49 per cent water). In the soils (four different soils having been studied), the limits in moisture content between which the germination of seeds can normally take place is much narrower. In two soils the germination could not take place at 20 per cent of the water-holding capacity, while in no case with the soils studied did it take place below this per cent. In all of the soils studied germination was retarded at 80 per cent of the saturation. In three soils out of four the best germination was observed at 40 per cent, followed by 60 per cent of the water-holding capacity.

16. The treatment of the sand or soil with a nutrient solution at the high moisture contents had very little, if any, effect on the germination of barley seeds. With the decrease in moisture content there was noticed some retardation in seed germination, when it was accompanied by the application of nutritive salts.

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ON THE EXTRACTION OF AMMONIA FROM SOIL

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INTRODUCTION

During the course of experiments conducted at the Ohio Agricultural Experiment Station upon the relationship existing between ammonification and other processes in soils, a comparison of the amounts of ammonia extracted from soils by water and 5 per cent hydrochloric acid was made. The results obtained are briefly outlined in this paper.

In a series of soil mixtures including treatments having an influence upon the amount of ammonia gradually being produced by the action of ammonifying organisms, upon added materials such as casein, the fixation of ammonia might be greater than if the total amount of ammonia formed was present at any one time. A water extract of these soils will not give the full amount of ammonia in them, but if it gives a proportional amount to that found by either distillation with magnesium oxide or extraction with acid, then for comparative purposes the ammonia found in the water extract would be just as useful as the larger amounts found by distillation or acid extraction.

McBeth (2) has recently shown that by making an acid extraction of soils he could obtain all the ammonia that could be obtained by distilling the soil with magnesium oxide, and at the same time get better-checking duplicates than could be obtained by distilling with MgO.

EXPERIMENTAL

The soils used were all surface soils (0–7 inches) which had been air-dried and ground sufficiently fine to pass through a 2-mm. sieve. Three distinct types of soil were included in this work; an acid silt loam, which is deficient in bases and organic matter, a basic black clay, well supplied with organic matter, and a very acid peat soil. These are designated as Wooster silt loam, Paulding clay, and peat.

While the data reported were chiefly obtained on different soil mixtures used in the investigations previously referred to, these same soils were also used in a preliminary experiment to determine the percentage of added ammoniacal nitrogen furnished by ammonium sulfate which could be recovered by extraction with water and with acid.

Methods

Portions of the soils were placed in 1-liter bottles and ammonium sulfate sufficient to supply 0.1484 gm. of nitrogen was added to half of the bottles. Water or 5 per cent hydrochloric acid was added at the rate of 500 cc. per 100 gm. of soil and extraction continued for 30 minutes with constant shaking in a machine. Nitrogen as ammonia was determined by distilling duplicate 200-cc. portions with 0.5 gm. of freshly-calcined magnesium oxide, first exactly neutralizing the acid extracts with sodium hydroxide.

The distillation was made in 500-cc. flasks, the distillate first passing through a second and smaller flask used as a scrubber, and from this through Pyrex glass tubing into Pyrex Erlenmeyer flasks; Pyrex glass being found as satisfactory as quartz for this purpose. As the acid in the receiving flask became

TABLE 1

Recovery of added nitrogen by water and 5 per cent hydrochloric acid

SOIL	NITROGEN RECOVERED							
	By Water				By Acid			
	Nitrogen from soil alone	From soil +0.1484 gm. nitrogen in ammonium sulfate	Increase	Per cent recovered	Nitrogen from soil alone	From soil +0.1484 gm. nitrogen in ammonium sulfate	Increase	Per cent recovered
	gm.	*gm.*	*gm.*		*gm.*	*gm.*	*gm.*	
Wooster silt loam	0.0	0.0941	0.0941	63.41	0.0073	0.1562	0.1489	100.00
Paulding clay	0.0	0.0586	0.0586	39.48	0.0117	0.1437	0.1320	88.94
Peat	0.0073	0.0949	0.0876	59.48	0.0155	0.1355	0.1200	80.86

very hot, the flasks were cooled under a water tap before the back titration was made with N/20 sodium hydroxid solution, methyl red being used as the indicator.

The results obtained by the above treatments are given in table 1.

The water extraction has failed to give more than 60 per cent of the added ammonia, while the acid extraction gave complete recovery in one case and more than 80 per cent in the other two cases.

Further and more conclusive data were obtained by determining both water and acid-soluble ammonia produced in a series of differently-treated soils that were being used in an investigation pertaining to the relation between sulfofication, nitrification, and ammonification in soils (1).

The different treatments for the Wooster soil with the water and acid-soluble ammonia obtained are given in table 2.

In this series of soils, twenty-seven 500-gm. portions of Wooster soil were weighed out into quart jars on March 16, 1917, and the treatments added as designated in the tabulation of results. These soils were kept under control so that optimum conditions of temperature and moisture prevailed. After

standing for a period of 17 weeks, the soils were thoroughly mixed and 400 gm. of each was extracted for 16 hours with 2500 cc. of distilled water free from ammonia and nitrates. These soil solutions were filtered through Berkfield filters, with an air pressure of 20 pounds. The solutions obtained were clear and free from sediment.

TABLE 2

Nitrogen as parts per million of soil, extracted from differently-treated samples of Wooster silt loam

TREATMENT			AMMONIACAL NITROGEN		INCREASE OF ACID OVER WATER EXTRACTION
Sulfur	Casein	Calcium carbonate	Extracted with water	Extracted with acid	
gm.	*gm.*	*gm.*	*p. p. m.*	*p. p. m.*	*p. p. m.*
0.0	0.00	0.0	0.0	0.0	0.0
0.0	1.75	0.0	132.3	196.0	64.0
0.0	0.00	2.0	0.0	0.0	0.0
0.0	1.75	2.0	0.0	14.0	14.0
0.0	0.00	0.0	0.0	0.0	0.0
0.0	1.75	0.0	131.2	183.0	52.0
0.0	0.00	2.0	0.0	0.0	0.0
0.0	1.75	2.0	0.0	10.5	10.5
0.5	0.00	0.0	32.8	60.0	32.2
0.5	1.75	0.0	328.0	416.0	88.0
0.5	0.00	2.0	0.0	0.0	0.0
0.5	1.75	2.0	0.0	51.0	51.0
0.5	0.00	1.0	28.4	45.5	17.1
0.5	1.75	1.0	240.6	324.0	84.0
0.5	0.00	0.5	45.0	47.0	2.0
0.5	1.75	0.5	207.7	306.0	99.0
0.5	0.00	0.0	48.1	89.0	41.0
0.5	1.75	0.0	328.1	455.0	127.0
0.5	0.00	2.0	0.0	0.0	0.0
0.5	1.75	2.0	87.5	131.0	43.5
0.5	0.00	1.0	37.1	70.0	32.9
0.5	1.75	1.0	278.0	378.0	100.0
0.5	0.00	0.5	42.5	87.0	44.5
0.5	1.75	0.5	288.7	390.0	103.0

All results are averages of duplicate determinations. A comparison of the amounts of ammonia extracted by water and acid from the soil with and without the addition of casein is shown in table 3.

When casein was not included in the treatment added to the soil, the amount of nitrogen as ammonia found by both the water and acid methods of extraction is much less than when casein was included in the treatment. With the smaller amounts of ammonia found in the soil without casein the acid extraction shows a high percentage increase, the acid extracting about 67 per cent more nitrogen as ammonia than did water. That this increase is not due to the acid extracting nitrogen from other than ammoniacal compounds is evident

from the fact that in six of the twelve samples, no nitrogen as ammonia was extracted by either water or acid treatment. In these six samples conditions were favorable for nitrification and any ammonia produced was changed to nitrates.

TABLE 3

Comparison of ammonia extracted from Wooster silt loam with and without the addition of casein by water and 5 per cent hydrochloric acid

TREATMENT			WATER-EXTRACTED AMMONIA	ACID-EXTRACTED AMMONIA	INCREASE OF ACID OVER WATER EXTRACTION	PER CENT INCREASE
Sulfur	Casein	Calcium carbonate				
With casein						
gm.	*gm.*	*gm.*	*p. p. m.*	*p. p. m.*	*p. p. m.*	
0.0	1.75	0.0	132	196	64	48.4
0.0	1.75	2.0	0	14	14	14.0
0.0	1.75	0.0	131	183	52	39.6
0.5	1.75	2.0	0	10	10	10.0
0.5	1.75	0.0	328	416	88	26.8
0.5	1.75	2.0	0	51	51	51.0
0.5	1.75	1.5	240	324	84	35.0
0.5	1.75	0.0	207	306	99	47.8
0.5	1.75	0.0	328	455	127	38.7
0.5	1.75	2.0	87	131	43	49.7
0.5	1.75	1.0	278	378	100	35.9
0.5	1.75	0.5	288	390	103	35.7
Without casein						
0.0	0.0	0.0	0	0	0	0.0
0.0	0.0	2.0	0	0	0	0.0
0.0	0.0	0.0	0	0	0	0.0
0.5	0.0	2.0	0	0	0	0.0
0.5	0.0	0.0	32	59	27	83.0
0.5	0.0	2.0	0	0	0	0.0
0.5	0.0	1.0	24	45	21	87.0
0.5	0.0	0.5	45	47	2	4.4
0.5	0.0	0.0	48	89	41	85.2
0.5	0.0	2.0	0	0	0	0.0
0.5	0.0	1.0	37	70	32	88.6
0.5	0.0	0.5	44	87	43	104.7

In the mixtures where ammonia was found, the oxidation of sulfur included in the treatment has depressed nitrification and the change from proteid to nitric nitrogen did not proceed completely, part of the ammonia formed remaining as ammonium sulfate. In each of these samples the ratio of the water-extracted ammonia to that extracted with acid is the same in each case, being 1.8 parts by acid for every part by water.

When casein was included in the treatments added to the soil, the amount of nitrogen as ammonia found was greatly increased and the amount extracted by water approaches that extracted by acid.

As in the case of the soils without added casein when conditions were favorable for nitrification, the amount of ammonia found is small, but when the acidity developed by the oxidation of added sulfur has not been neutralized by calcium carbonate, the amount of ammonia found is high. In eight such cases the ratio of the water to acid-extracted ammonia is 1.3 parts by acid extraction to each part extracted with water.

Extraction of ammonia from Paulding clay

This soil is a very basic clay soil and differs very much from the Wooster silt loam. No casein was added to this soil, as it contains much natural organic matter. The results with this soil are found in table 4.

TABLE 4

Extraction of ammoniacal nitrogen from basic Paulding clay

TREATMENT		AMMONIACAL NITROGEN		INCREASE OF ACID OVER WATER EXTRACTION
Sulfur	Calcium carbonate	Extracted with water	Extracted with acid	
gm.	*gm.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0.0	0.0	10.9	78	67.1
0.0	0.5	10.9	56	45.1
0.0	0.0	10.9	35	24.1
0.0	0.5	0.0	52	52.0
0.5	0.0	10.9	44	33.1
0.5	0.5	10.9	47	36.1
0.5	0.25	9.8	64	44.2
0.5	0.0	9.8	78	68.2
0.5	0.5	10.9	52	41.1
0.5	0.25	16.9	54	37.1

With this basic clay soil which contains 10 parts per million of water-soluble nitrogen as ammonia, the 5 per cent hydrochloric acid solution has been able to extract an average of 50 parts per million of nitrogen.

With this clay soil the ratio of the water- to the acid-extracted ammonia is 4.6 parts of acid-extracted ammonia for every part extracted by water.

Extraction from peat

The peat used was an acid peat of rather raw texture. The solution obtained from this soil was highly colored but without sediment. The results for the peat are given in table 5.

The high figures obtained for ammonia from this peat by acid extraction might cause one to believe that other than ammonium compounds had been extracted by the acid, but it must be remembered that in the preliminary work, the 5 per cent hydrochloric acid was able to recover only 80 per cent of the added nitrogen from this peat.

TABLE 5

Extraction of ammoniacal nitrogen from an acid peat

TREATMENT		AMMONIACAL NITROGEN		INCREASE OF ACID OVER WATER EXTRACTION	PER CENT INCREASE
Sulfur	Calcium carbonate	Extracted with water	Extracted with acid		
gm.	*gm.*	*p. p. m.*	*p. p. m.*	*p. p. m.*	
0.00	0.00	259	525	266	102.7
0.00	1.50	122	210	88	72.1
0.00	0.00	252	532	280	111.1
0.00	1.50	115	203	88	76.5
0.15	0.00	357	598	241	67.5
0.15	1.50	399	684	285	71.4
0.15	0.75	406	595	189	46.5
0.15	0.30	402	595	193	48.0
0.15	0.00	392	630	238	60.7
0.15	1.50	318	630	312	98.1
0.15	0.75	420	700	280	66.6
0.15	0.30	403	626	223	55.3
0.00	0.00	252	544	292	115.8

SUMMARY

While in no case has the water extraction given the full amount of ammonia from the different soils, yet in each group a certain ratio appears to exist between the amounts extracted by the two methods, and for comparative use, the ammonia found in the water extract would be just as useful as the somewhat larger amount found by extracting the soil with 5 per cent hydrochloric acid.

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THE OCCURRENCE OF BACTERIUM LACTIS VISCOSUM IN SOIL

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Little is known concerning the natural habitat of most microörganisms, hence any contribution to this phase of bacteriology will furnish welcome and valuable information to students of this subject.

During the autumn of 1915 at the New Jersey Agricultural Experiment Station, in the course of certain bacteriological investigations of soil, a colony resembling *Bacterium lactis viscosum* was found on a plate of beef broth agar. The plate had been poured from a dilution of 1 to 50,000. The soil was a Sassafras sandy loam which had not been manured with cow dung for at least 3 years. The writer's attention was directed to this colony on account of its great viscosity and its reddish tint. After isolation in pure culture on agar slants, its morphological and cultural characteristics were determined, including its action on milk. The organism corresponded with Conn's description in every particular except that in the soil culture the reddish color was somewhat more pronounced on solid media. It also agreed very well with the stock laboratory culture of *Bact. lactis viscosum*.

The next year (1916), another organism of this type was isolated from a large decayed soybean nodule. It made appreciable growth on Ashby's mannite agar, which is nearly nitrogen-free. On account of the very viscid nature of the colony it was transferred to broth agar and the cultural characteristics of the bacterium determined in the usual way. These tests confirmed the indication that the organism was *Bact. lactis visocsum*. It produced some pigment but this character was not nearly as pronounced as in the organism first isolated. After three transfers on broth agar, it was replanted on Ashby's mannite agar but no growth was observed. The organism had apparently lost its power of living on this nitrogen-poor medium. Perhaps like many other freshly-isolated soil organisms it is able for a short time to fix some atmospheric nitrogen.

The soybean field from which this second organism was isolated, was located within a hundred yards of a heap of horse manure but no cow dung had been added to the soil in several years. Cattle had not been allowed to roam on either field for over twenty years. The soil on which the soybeans grew was a Penn shaley loam.

The presence of this organism in soils of two different types, indicates that the soil is probably a natural medium for the development of this widely

distributed and trouble-causing organism. From at least three cases of slimy milk in the state of New Jersey during the past two years, identical cultures of this organism were obtained. If the soil is a home of this bacterium, then the sporadic outbreaks of ropy milk in dairies throughout the country may be more readily understood. At first usually but one teat of the cow is affected, then it spreads rapidly to the other teats or other animals unless promptly checked. Unless all utensils which come in contact with ropy milk are thoroughly sterilized, they may harbor the organisms and be a potent source of trouble for a long time. The organism does not form spores, but there are many other non-spore-forming bacteria in the soil. Perhaps the slime produced serves as a sort of protection and aids it to multiply and live in the soil.

SUMMARY

Two organisms, corresponding to written descriptions and laboratory cultures of *Bact. lactis viscosum*, were isolated from two different soils, which had not received applications of cow dung for several years. It is probable that the soil is a natural habitat of this organism.

INDEX

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